

Physical parameters of 62 eclipsing binary stars using the ASAS-3 data–I

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ABSTRACT

We present a detailed light curve analysis of publicly available V band observations of 62 binary stars, mostly contact binaries, obtained by the All Sky Automated Survey (ASAS)-3 project between 2000 and 2009. Eclipsing binaries are important astronomical targets for determining the physical parameters of component stars from the geometry. They provide an independent direct method of measuring the radii of stars. We improved the ASAS determined periods, ephemeris and obtained the Fourier parameters from the phased light curves of these 62 stars. These Fourier parameters were used for preliminary classification of the stars in our sample. The phased light curves were then analysed with the aid of the Wilson-Devinney light curve modelling technique in order to obtain various geometrical and physical parameters of these binaries. The spectroscopic mass ratios as determined from the radial velocity measurements available in the literature were used as one of the inputs to the light curve modelling. Thus reliable estimations of parameters of these binaries were obtained with combined photometric and spectroscopic data and error estimates were made using the heuristic scan method. For several systems in the sample, the solutions were obtained for the first time and would serve as a good source in the future for the light curve analysis based on the more precise follow-up CCD photometric observations. Out of 62 stars in the sample, photometric analysis of 39 stars are presented here for the first time using the ASAS photometry and precise spectroscopic mass ratios. From the analysis, we found 54 contact binaries, 6 semi-detached binaries and 2 detached binaries. The Fourier parameters in the a_2 – a_4 plane were used for preliminary classification and the final classification was done based on the Roche lobe geometry obtained from the light curve modelling.

Key words: binaries: eclipsing - binaries: close - stars: fundamental parameters - stars : evolution - stars: magnetic fields: spots

1 INTRODUCTION

Eclipsing binaries play an important astrophysical tool for the study of star formation, stellar structure, in testing the theories of stellar evolution and determining the physical properties of stars. They have been used as standard candles (Paczynski 1997) to determine the size and structure of the Galaxy, as well as to constrain the cosmological distance ladder (Bonanos et al. 2006). They are the potential targets since the orbital motion, inferred from the radial velocity curves and the shape of eclipses from the photometric light curves can be entirely explained by the gravitation laws and geometry of the system. They are also useful for distance determinations since the radii and temperatures of the com-

ponents can be reliably determined from the combined photometry and spectroscopy (Vilardell et al. 2010).

Contact binaries, also known as the W UMa stars, are low mass eclipsing binaries consisting of ellipsoidal components with orbital periods less than 1 day, usually in the range $0.2 < P < 0.8$ day, with continuously changing brightness (Kang et al. 2002; Percy 2007). They consist of solar type main-sequence components which fill their Roche lobes and share a common outer envelope at the inner Lagrangian point. The maxima of the light curves are rounded as the shapes of the two stars are strongly tidally distorted because of their proximity to one another (Shu 1982). Most of the W UMa type binaries have temperatures of the components roughly equal because of sharing a common envelope with the same entropy, thereby making the effective temperatures almost equal over the surfaces (Paczynski et al.

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2006). There is also a subclass of contact binaries with temperature difference of 1000 K or larger between the components. Csizmadia & Klagyivik (2004) called these as B-type contact binaries. In this paper, we follow the definition of B-type contact binaries as given by Csizmadia & Klagyivik (2004). B-type contact binaries are sometimes called ‘Poor thermal contact binaries’ (Rucinski & Duerbeck 1997).

The ASAS project started in 1997 with the goal of photometrically monitoring millions of stars brighter than 14 mag in the V band and distributed all over the sky (Pojmanski 1997, 2002). The ASAS-3 system is located at Las Campanas Observatory and is operating since August 2000. It is equipped with 200/2.8 Minolta telephoto lenses and covers 8.8×8.8 deg of the sky through the standard V and I filters. So far, ASAS has discovered more than 50000 variables located south of declination $+28^\circ$ and nearly 10000, among these newly identified variables, are eclipsing binaries. For more details about the ASAS project and the instruments, we refer the reader to Pojmanski (1997, 1998, 2002). These newly discovered binaries, among the others, are very valuable and their determination of absolute physical parameters will help to address several key problems related to stellar astrophysics.

ASAS database has time series photometric measurements of a large number of eclipsing binary stars. The light curves of these stars can provide reliable information about various parameters, once the mass ratios from the radial velocity measurements are available. The evolution of stars with cool convective envelopes; notably, of binary stars, are greatly affected by the dynamo-driven mass loss, magnetic braking and tidal friction which cause angular momentum loss from the orbit (Parihar et al. 2009). Therefore, enriching the total sample of new eclipsing binary stars with their parameters preliminary determined from databases like ASAS and their future follow-up regular observations using more precise CCD photometric data and spectroscopic radial velocity measurements will enhance our knowledge in understanding the nature, structure and evolution of binary stars.

Recently, ASAS photometric database has been used by Helminiak et al. (2009) to determine the absolute and physical parameters for a sample of 18 detached binaries using the spectroscopic values of mass ratio q_{sp} obtained from their new radial velocity measurements. Out of 18 eclipsing binaries in their sample, 15 are new, discovered by ASAS.

The main rationale of this paper is to exploit the available ASAS photometric data of 62 binary stars which have complementary well-defined radial velocity measurements in the literature in order to determine their geometrical and physical parameters. In Section 2, we describe the criteria to select the sample in our present study. In Section 3, we describe a method to improve the period as determined by ASAS. Section 4 deals with the determination of Fourier parameters from the phased light curves and classification using the Fourier coefficients in the a_2 – a_4 plane. In Section 5, we describe the light curve analysis using the WD light curve modelling technique to estimate the various geometrical and physical parameters of the 62 ASAS stars. In Section 6, we present results obtained from the light curve modelling and compare to those in the literature, wherever available. Section 7 describes various relations for contact

binaries. Finally, in Section 8, we present summary and conclusions of this study.

2 SAMPLE SELECTION CRITERIA

2.1 The data

The number of photometric light curves of eclipsing binary stars have surpassed their spectroscopic radial velocity measurements with the advent of various all sky automated photometric surveys. Rucinski & his collaborators (hereafter RC, Lu & Rucinski 1999; Rucinski & Lu 1999; Rucinski et al. 2000; Lu et al. 2001; Rucinski et al. 2001, 2002; Rucinski 2002; Rucinski et al. 2003; Pych et al. 2004; Rucinski et al. 2005; Pribulla et al. 2006; Duerbeck & Rucinski 2007; Rucinski & Duerbeck 2006; Pribulla et al. 2007; Rucinski et al. 2008; Pribulla et al. 2009a,b) started a project to obtain precise radial velocity measurements of a large number of binary stars. In practice, physical parameters of eclipsing binary stars are derived from the photometric light curve modelling which in general, require accurate and precise mass ratio as an input obtained from the spectroscopic radial velocity measurements.

We searched for eclipsing binaries from the ASAS online database, which have well-defined determinations of mass ratios available from radial velocity measurements obtained by RC. We found 67 stars in the ASAS database corresponding to the coordinates of identifiers of stars in the RC’s sample using the SIMBAD database. However, light curves of the 5 ASAS stars turned out to be very noisy after they were phased with their respective periods as given in the database. The light curves of these stars could not even be improved using the period determination technique as described in Section 3. Therefore, these stars were rejected for further analysis. These stars were 002524–4655.5 (BQ Phe), 050702–0047.6 (V1363 Ori), 124015–1848.0 (SX Crv), 131223+0239.3 (KZ Vir) and 164824+1708.1 (V918 Her). Our final sample, thus, consisted of 62 eclipsing binary stars. Light curves of each of the 62 stars were then examined carefully and outliers were removed after visual inspection. All the selected targets have evenly covered V-band light curves with an internal accuracy $\sim 0.03 - 0.11$ mag having number of data points between 96 (062605+2759.9) and 1221 (204628–7157.0). The data for these 62 eclipsing binary stars, mostly contact binaries from the ASAS-3 database along with their spectroscopically determined mass ratios are used to model the light curves in order to obtain their various geometrical and physical parameters. The parameters determined for these 62 stars in this work, in turn, can be used as inputs to the analysis of more accurate and precise light curves based on follow-up observations. All the systems have their ASAS photometry available online¹. On the average, the number of observations per star is of the order of several hundreds in the ASAS database. These stars have a good phase coverage of their light curves.

¹ <http://www.astrouw.edu.pl/asas>

2.2 Radial velocity and its importance

It is a widely accepted fact that physical parameters of binary stars obtained from the photometric light curve modelling are reliable only when the spectroscopically determined mass ratio is used as an input in the photometric light curve modelling and kept fixed. In the light curve modelling of binary stars, mass ratio is the most important parameter and should be obtained from precise spectroscopic radial velocity measurements. It plays an important role in deriving the accurate masses and radii of the components, which are the key parameters in understanding the structure and evolution of binary stars. It has been seen from the literature that determination of mass ratio from the photometric light curve modelling is exceedingly difficult. For a partially-eclipsing binary, it is impossible to reliably measure the mass ratio from the photometric modelling even with the highly accurate photometric data. On the other hand, the mass ratios determined from the photometric data may be reliable only for a total-eclipse configuration of the binary systems as such light curves show characteristic inner contacts with duration of totality setting a strong constraint on the (q, i) pair (Rucinski 2001). The literature is crowded with physical parameter estimations using the photometric mass ratio (q_{ph}) obtained from the light curve modelling for many partially eclipsing systems which were later modified when subsequent radial velocities became available.

3 UPDATING THE ASAS PERIOD

The automated surveys like ASAS, offer a unique opportunity to study the properties of a large number of stars. However, the processing of huge amount of data in these databases is quite challenging, even when looking at seemingly small issues such as period determination and classification (Derekas et al. 2007). Although the periods determined for most of the stars in the ASAS database is reasonably accurate (except 185318+2113.5), we have found that the ASAS periods need to be updated to the improved quality of data available at present. Periods of variable stars in the ASAS database were in general determined very well during the preparation of the catalog. However, the data for some parts of the sky were analysed many years ago, when the time span was much shorter. Therefore, the accuracy was not good as it can be obtained today.

It has been found that the period determination can be further improved by the use of methods such as string lengths (Derekas et al. 2007) or minimization of entropy method (Deb et al. 2009). The new period determinations result in the improvement of the ASAS periods to fifth or sixth decimal place. This period improvement has resulted in revealing the accurate shapes of the phased light curves of the ASAS eclipsing binaries. In practice, when the period is accurate enough, the phased data are clearly arranged with minimum scatter due to noise. On the other hand, when the light curve is folded into phase by an incorrect period, the data gets randomized and more scattered.

We have used the minimization of entropy (hereafter, ME) method to improve and update the period as determined by ASAS which is based on the minimization of the information entropy of the light curve (Cincotta et al. 1995).

It is based on the fact that the light curves in the phase-magnitude (Φ, x) space are more ordered when the phases are determined using the correct period, where phase (Φ) is defined as:

$$\Phi = \frac{(t - t_0)}{P} - \text{Int} \left(\frac{(t - t_0)}{P} \right), \quad (1)$$

where t_0 is the initial epoch of the variable star light curve and t is the time of observations. The value of Φ is from 0 to 1, corresponding to a full cycle of the orbital period P . Int denotes the integer part of the quantity. The light curve data (t_i, x_i) is phased into the phase-magnitude space according to the trial period. Now the phase-magnitude space is divided into $n \times m$ bins. Let μ_{ij} be the number of observations in the (i, j) bin normalized by the total number of the data, then the entropy S is

$$S = \sum_{i=1}^n \sum_{j=1}^m \mu_{ij} \ln(\mu_{ij}), \quad (2)$$

for all $\mu_{ij} > 0$. If the trial period is not the true one, the light curve points will be distributed uniformly in the (Φ, x) plane and the entropy will be maximum. On the other hand, if the trial period matches with the actual period, the points will be limited into a small regions of the plane and the entropy will then be minimum, which will correspond to the best period of the light curve. In our case, we applied the ME method around $\pm 1\%$ of the ASAS-determined periods. An example of the period improvement is shown in Fig. 1. The typical improvement results in a change in the fifth or sixth decimal place. For 185318+2113.5, we have found that the ASAS period is not correct, as no significant periodicity can be confirmed from the phased light curve with $P_{\text{ASAS}} = 21.84685$ days. For preliminary period determination of this star only, we have used the phase dispersion minimization method (hereafter PDM, Stellingwerf 1978). In Fig. 2, we show the PDM results applied to the light curve of ASAS 185318+2113.5. The three dominant peaks of the PDM results are 0.493326d, 0.246658d and 0.395712d in increasing Θ values, where Θ is defined as in Stellingwerf (1978). We also tried to improve the most dominant period 0.493326d, using the ME method. ME method is run around $\pm 1\%$ of the period 0.493326d. The period is found to be $P_{\text{ME}} = 0.493322\text{d}$. In this case, the period determined by both PDM and ME methods are nearly identical. The light curve of ASAS 185318+2113.5 phased with the ASAS determined period P_{ASAS} and our determined period P_{ME} are shown in Fig. 3. Our photometric analysis reveals that the star is at a very low inclination angle $i[^\circ] = 41.59 \pm 2.78$ and is a B-type contact binary with $\Delta T = 2316 \pm 647$ K. However, little noisiness of the ASAS-3 data and its low amplitude makes this star a good candidate for accurate follow-up observations.

In Table 1, we list the serial numbers, ASAS identification names, SIMBAD identification names, J2000 coordinates, ASAS Periods (P_{ASAS}), updated periods determined using the ME method (P_{ME}), type of binary determined from the light curve analysis, V band magnitudes, infrared ($J-K$) color indices (Cutri et al. 2003) and epochs of minimum light determined from the light curve modelling. In Table 2, we list the spectral type, radial velocity semi-

Table 1. Basic information of the ASAS stars used for the analysis

Serial No.	ASAS ID	Other ID	$\alpha(2000)$	$\delta(2000)$	P _{ASAS} [d]	P _{ME} [d]	Type	V [mag]	J-K [mag]	Epoch(PHOEBE) (JD-2450000)
1	003628+2132.3	DZ Psc	00 36 27.95	+21 32 14.63	0.366125	0.366131	A	11.126	0.253(35)	2970.55742(53)
2	011638-3942.S	AD Phe	01 16 38.07	-39 42 31.32	0.37992	0.379919	W	10.290	0.400(33)	1903.57897(27)
3	012104+0736.3	AQ Psc	01 21 03.56	+07 36 21.63	0.475611	0.475604	A	8.67	0.255(30)	3653.71608(47)
4	014656-0945.1	TT Cet	01 46 56.50	-09 45 09.74	0.48596	0.485952	B	10.9	0.250(29)	5103.85398(27)
5	014854-2053.6	TW Cet	01 48 54.14	-20 53 34.60	0.316849	0.316851	A	10.7	0.492(38)	4476.61655(09)
6	023833-1417.9	DY Cet	02 38 33.18	-14 17 56.73	0.440790	0.440790	A	9.8	0.258(34)	3644.73772(18)
7	024952+0856.3	EE Cet	02 49 52.26	+08 56 17.95	0.37992	0.379925	W	9.6	0.280(47)	2643.60106(42)
8	030701-5608.1	SZ Hor	03 07 01.23	-56 08 04.45	0.62511	0.625102	B	11.214	0.217(31)	4314.86179(21)
9	030953-0653.6	UX Eri	03 09 52.74	-06 53 33.56	0.44528	0.445289	W	10.639	0.374(33)	2954.68457(31)
10	033459+1742.6	V1123 Tau	03 34 58.54	+17 42 38.04	0.399946	0.399947	W	9.97	0.246(50)	2621.64645(28)
11	034814+2218.9	EQ Tau	03 48 13.43	+22 18 50.92	0.341347	0.341350	A	11.196	0.376(28)	4846.56462(27)
12	034928+0833.4	V1128 Tau	03 49 27.77	+12 54 43.84	0.305372	0.305371	W	9.353	0.454(30)	3751.85398(13)
13	035153-1031.8	BV Eri	03 51 53.34	-10 31 49.46	0.507654	0.507655	B	8.32	0.221(33)	4300.91691(25)
14	041209-1028.2	YY Eri	04 12 08.85	-10 28 09.96	0.321499	0.321498	W	8.41	0.443(34)	3454.51668(15)
15	042925-3334.6	CT Eri	04 29 24.79	-33 34 34.33	0.63419	0.634196	B	10.22	0.215(36)	5113.78813(36)
16	051114-0833.4	ER Ori	05 11 14.50	-08 33 24.66	0.4234	0.423406	W	10.00	0.317(31)	1967.52536(27)
17	051832-6813.6	RW Dor	05 18 32.54	-68 13 32.76	0.285461	0.285463	W	10.80	0.573(33)	3466.52950(11)
18	062605+2759.9	AH Aur	06 26 04.93	+27 59 56.40	0.247053	0.494106	A	10.176	0.329(28)	2970.78867(66)
19	064558-0017.5	DD Mon	06 45 57.83	-00 17 31.90	0.56803	0.568019	ESD	11.1	0.388(35)	3051.72047(22)
20	071058-0352.8	V753 Mon	07 10 57.85	-03 52 43.19	0.67705	0.677045	ESD	8.34	0.203(32)	2701.61206(17)
21	073246-2047.5	TY Pup	07 32 46.23	-20 47 31.07	0.81925	0.819243	A	8.62	0.257(61)	1876.71731(25)
22	073338-5007.4	HI Pup	07 33 38.21	-50 07 25.05	0.432618	0.432618	A	10.70	0.349(30)	1924.66065(40)
23	073905-0239.1	V868 Mon	07 39 04.83	-02 39 05.54	0.637704	0.637704	A	8.9	0.160(33)	3745.73825(63)
24	084002+1900.0	TX Cnc	08 40 01.71	+18 59 59.51	0.382882	0.382883	W	10.026	0.355(27)	4409.86331(45)
25	084108-3212.1	TZ Pyx	08 41 08.26	-32 12 03.02	2.318500	2.318530	ED	10.67	0.083(33)	3805.78546(51)
26	100141+1724.5	XY Leo	10 01 40.43	+17 24 32.70	0.284098	0.284101	W	9.67	0.701(41)	2733.60478(28)
27	100234+1702.8	XZ Leo	10 02 34.19	+17 02 47.14	0.487736	0.487736	A	10.29	0.171(30)	3339.81443(30)
28	100248+0105.7	Y Sex	10 02 47.96	+01 05 40.35	0.41982	0.487736	A	9.97	0.278(32)	4589.56751(21)
29	101602-0618.5	XX Sex	10 02 47.96	+01 05 40.35	0.540111	0.540108	A	9.32	0.243(38)	4164.67601(40)
30	104033+1334.0	UZ Leo	10 40 33.19	+13 34 00.86	0.61806	0.618057	A	9.75	0.208(30)	3809.70840(26)
31	105030-0241.7	VY Sex	10 50 29.72	-02 41 43.05	0.443432	0.443433	W	9.01	0.346(38)	4918.58983(21)
32	110211+0953.7	AM Leo	11 02 10.89	+09 53 42.69	0.365798	0.365799	W	9.31	0.328(30)	3739.83444(20)
33	110505+0509.1	AP Leo	11 05 05.02	+05 09 06.42	0.430356	0.430358	A	9.53	0.368(33)	4656.47307(33)
34	120103+1300.5	AG Vir	12 01 03.50	+13 00 30.02	0.64265	0.642648	A	8.52	0.145(32)	3190.48336(47)
35	121206+2232.0	CC Com	12 12 06.20	+22 31 58.00	0.220686	0.220686	W	11.00	0.741(26)	3012.86303(16)
36	123300+2642.9	RW Com	12 33 00.28	+26 42 58.38	0.237348	0.237346	W	11.00	0.618(34)	4918.69861(20)
37	131032-0409.5	PY Vir	13 10 32.22	-04 09 32.59	0.311251	0.311248	ESD	9.60	0.572(38)	5002.62738(25)
38	134607+0506.9	HT Vir	13 46 06.75	+05 06 56.27	0.407672	0.407672	ESD	7.16	0.324(30)	4919.78397(20)
39	141726+1234.1	VW boo	14 17 26.03	+12 34 03.45	0.342315	0.342315	A	10.539	0.467(29)	2840.61141(20)
40	141937+0553.8	NN Vir	14 19 37.74	+05 53 46.66	0.480687	0.480688	A	7.64	0.240(37)	3576.56765(36)
41	143504+0906.8	CK Boo	14 35 03.76	+09 06 49.39	0.355154	0.355152	A	9.09	0.295(44)	2670.83810(29)
42	144803+1356.7	EL Boo	14 48 03.40	+13 56 41.19	0.413767	0.413766	ESD	9.35	0.282(34)	4633.62388(64)
43	152243+1615.7	OU Ser	15 22 43.47	+16 15 40.74	0.148382	0.296768	A	8.25	0.376(31)	4891.85575(51)
44	153152-1541.1	VZ Lib	15 31 51.76	-15 41 10.19	0.358259	0.358256	A	10.341	0.379(35)	4487.86967(22)
45	155649+2216.0	AU Ser	15 56 49.40	+22 16 01.00	0.386498	0.386498	A	10.50	0.509(28)	4299.48288(29)
46	164121+0030.4	V502 Oph	16 41 20.86	+00 30 27.37	0.45339	0.453388	W	8.53	0.345(29)	4701.54142(29)
47	165717+1059.8	V2357 Oph	16 57 16.76	+10 59 51.38	0.207783	0.415568	A	10.52	0.426(31)	4691.59160(93)
48	171358+1621.0	AK Her	17 13 57.82	+16 21 00.61	0.421522	0.421524	A	8.51	0.313(34)	5071.56586(24)
49	173356+0810.0	V2377 Oph	17 33 56.05	+08 09 57.81	0.425403	0.425406	W	8.56	0.333(34)	3652.52046(66)
50	175332-0354.9	V2610 Oph	17 53 32.26	-03 54 55.33	0.42652	0.426514	ESD	9.20	0.393(34)	2508.56035(42)
51	180921+0909.1	V839 Oph	18 09 21.27	+09 09 03.63	0.409	0.409008	A	8.984	0.344(28)	3547.70359(15)
52	182913+0647.3	V2612 Oph	18 29 13.01	+06 47 13.72	0.3753	0.375309	W	9.44	0.279(38)	4234.79641(40)
53	185318+2113.5	V1003 Her	18 53 17.54	+21 13 32.74	21.84685	0.493322	B	9.795	0.234(32)	3099.90625(96)
54	193524+0550.3	V417 Aql	19 35 24.12	+05 50 17.66	0.370306	0.370314	W	10.647	0.354(33)	4216.88607(13)
55	194813+0918.5	OO Aql	19 48 12.65	+09 18 32.38	0.506786	0.506794	A	9.51	0.440(36)	5070.71438(18)
56	203113+0513.2	MR Del	20 31 13.47	+05 13 08.50	0.52169	0.521692	ED	11.01	0.624(28)	4742.53633(35)
57	204628-7157.0	MW Pav	20 46 27.76	-71 56 58.48	0.795	0.794994	A	8.80	0.229(30)	1887.51161(26)
58	205710+1939.0	LS Del	20 57 10.29	+19 38 59.22	0.36384	0.363842	W	8.654	0.308(37)	4628.80678(97)
59	222257+1619.4	BB Peg	22 22 56.89	+16 19 27.84	0.361487	0.361502	W	10.967	0.388(28)	3586.70831(18)
60	233655+1548.1	V407 Peg	23 36 55.37	+15 48 06.43	0.63688	0.636882	A	9.28	0.181(33)	5084.67263(51)
61	234535+2528.3	V357 Peg	23 45 35.06	+25 28 18.94	0.57845	0.578450	A	9.06	0.178(34)	4693.78602(34)
62	234718-0805.2	EL Aqr	23 47 18.35	-08 05 12.09	0.48141	0.481412	A	10.572	0.249(35)	4456.57167(35)

Table 2. Spectral type and radial velocity information for the ASAS stars

ASAS ID	Spectral type	K_1 [km s ⁻¹]	σK_1 [km s ⁻¹]	K_2 [km s ⁻¹]	σK_2 [km s ⁻¹]	Mass ratio (q)	References
003628+2132.3	F7V	40.39	2.64	297.98	4.18	0.136(10)	7
011638-3942.5	F9/G0V	89.04	3.10	242.41	1.42	0.370(10)	11
012104+0736.3	F5/8V	59.50	0.40	263.30	1.90	0.226(02)	1, 13
014656-0945.1	F4V	107.90	10.30	276.00	27.00	0.39(07)	11
014854-2053.6	G1V	157.40	3.26	209.66	3.84	0.75(03)	11
023833-1417.9	F5V	90.84	2.11	255.40	2.28	0.356(9)	13
024952+0856.3	F8V	84.05	1.24	266.92	1.54	0.315(5)	6
030701-5608.1	F3V	109.51	6.60	231.34	13.50	0.47(04)	11
030953-0653.6	F9V	91.75	1.55	245.76	1.86	0.373(21)	11
033459+1742.6	G0V	71.08	0.84	254.71	0.84	0.279(4)	12
034814+2218.9	G2V	112.41	1.43	254.38	2.42	0.442(7)	4
034928+1254.7	F8V	130.48	1.27	244.19	1.28	0.534(6)	12
035153-1031.8	F3/4V	65.71	2.90	221.10	9.90	0.30(02)	11
041209-1028.2	G3V	107.30	2.27	242.57	2.56	0.401	11
042925-3334.6	F2/3V	68.30	14.90	229.10	48.00	0.30(09)	11
051114-0833.4	F7/8V	147.98	2.30	225.48	2.35	0.656(12)	13
051832-6813.6	G4/5V	134.35	3.46	213.06	4.65	0.63(03)	11
062605+2759.9	F7V	47.20	1.16	279.61	2.80	0.169(59)	1
064558-0017.5	G0V	133.32	3.06	198.85	3.18	0.670(19)	13
071058-0352.8	A8V	176.07	0.97	170.76	0.97	1.031(9)	3
073246-2047.5	F3V	55.68	5.52	226.80	15.40	0.25(03)	11
073338-5007.4	F6V	50.20	15.40	265.20	17.20	0.19(06)	11
073905-0239.1	F2V	91.21	1.83	244.67	2.22	0.373(8)	13
084002+1900.0	F8V	100.77	0.82	221.67	0.91	0.455(11)	9
084108-3212.1	A8/9V	126.22	2.09	130.79	1.52	0.965(20)	11
100141+1724.5	K0V	144.65	1.10	198.41	1.11	0.729(7)	10
100234+1702.8	A8/F0V	262.55	2.60	91.49	1.80	0.348(29)	2
100248+0105.7	F5/6V	54.96	2.30	281.94	2.86	0.195(8)	13
101602-0618.5	F3V	25.80	0.45	258.51	1.54	0.100(2)	10
104033+1334.0	A9/F1V	79.69	1.12	262.87	1.89	0.303(24)	2
105030-0241.7	F9.5	74.33	0.91	237.30	1.32	0.313(5)	7
110211+0953.7	F5V	115.56	0.97	251.98	1.17	0.459(4)	10
110505+0509.1	F8V	78.20	2.30	263.10	2.90	0.297(09)	1
120103+1300.5	A5V	93.39	1.06	244.24	1.97	0.382(21)	9
121206+2232.0	K4/5V	124.83	1.34	237.00	1.09	0.527(6)	10
123300+2642.9	K2/5V	112.04	1.28	237.70	1.29	0.471(6)	13
131032-0409.5	K1/2V	152.78	0.77	197.58	0.77	0.773(5)	12
134607+0506.9	F8V	169.39	1.00	208.54	1.00	0.812(8)	5
141726+1234.1	G5V	101.39	1.07	236.74	1.03	0.428(5)	13
141937+0553.8	F0/1V	112.68	0.71	229.28	1.24	0.491(11)	2
143504+0906.8	F7/8V	31.66	0.78	285.31	1.63	0.111(52)	2
144803+1356.7	F5V	64.19	1.70	259.07	1.89	0.248(7)	13
152243+1615.7	F9/G0V	40.59	0.59	234.24	0.69	0.173(17)	3
153152-1541.1	G0V	84.10	3.84	252.20	4.55	0.33(4)	5, 15
155649+2216.0	G4V	138.77	1.33	195.64	1.34	0.709(8)	13
164121+0030.4	G0V	82.71	1.03	246.70	1.00	0.335(9)	8
165717+1059.8	G5V	44.12	1.63	190.93	2.90	0.231(10)	7
171358+1621.0	F4V	70.52	1.12	254.40	2.27	0.277(24)	9
173356+0810.0	G0/G1V	159.64	0.70	62.99	0.62	0.395(12)	5
175332-0354.9	F8/G2V	72.06	2.06	247.42	2.08	0.291(9)	13
180921+0909.1	F7V	84.82	1.33	278.52	2.01	0.305(24)	2
182913+0647.3	F7V	71.33	0.66	249.09	0.89	0.286(3)	10
185318+2113.5	A7	64.07	0.94	171.91	0.94	0.373(6)	12
193524+0550.3	F7V	97.00	1.60	268.20	2.70	0.362(7)	1, 13
194813+0918.5	F9V	153.03	0.93	180.81	1.14	0.846(7)	10
203113+0513.2	K2V	135.74	1.27	148.32	1.27	0.915(12)	13
204628-7157.0	F3IV/V	52.35	1.15	229.34	3.52	0.228(8)	14
205710+1939.0	F5/8V	69.00	1.60	184.80	2.20	0.375(10)	1, 13
222257+1619.4	F7V	97.20	1.50	270.20	2.50	0.360(06)	1, 13
233655+1548.1	F0V	63.92	1.12	250.02	1.16	0.256(6)	12
234535+2528.3	F2V	93.78	0.86	234.08	0.87	0.401(4)	12
234718-0805.2	F3V	53.38	1.53	263.34	4.38	0.203(8)	4

1. Lu & Rucinski (1999); 2. Rucinski & Lu (1999); 3. Rucinski et al. (2000); 4. Rucinski et al. (2001); 5. Lu et al. (2001); 6. Rucinski et al. (2002); 7. Rucinski et al. (2003); 8. Pych et al. (2004); 9. Pribulla et al. (2006); 10. Pribulla et al. (2007); 11. Duerbeck & Rucinski (2007); 12. Rucinski et al. (2008) ; 13. Pribulla et al. (2009b); 14. Rucinski & Duerbeck (2006); 15. Szalai et al. (2007)

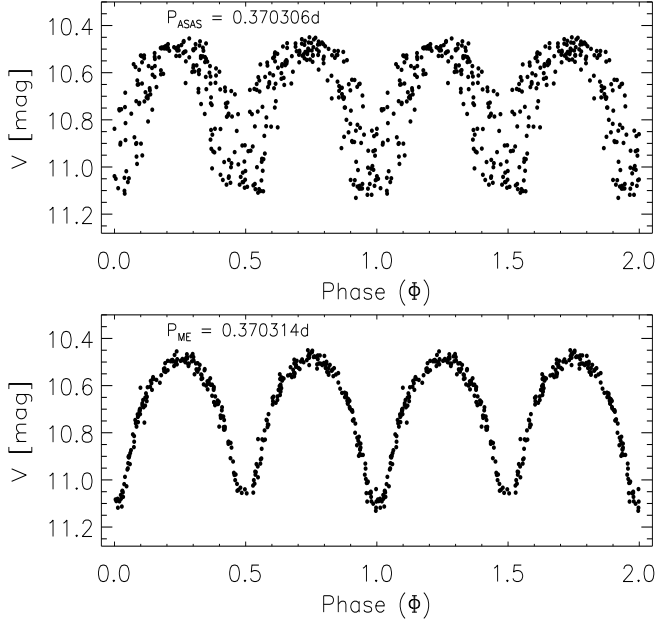


Figure 1. An example (193524+0550.3) of improvements in the ASAS period (top) determined by using the minimization of entropy (bottom) method.

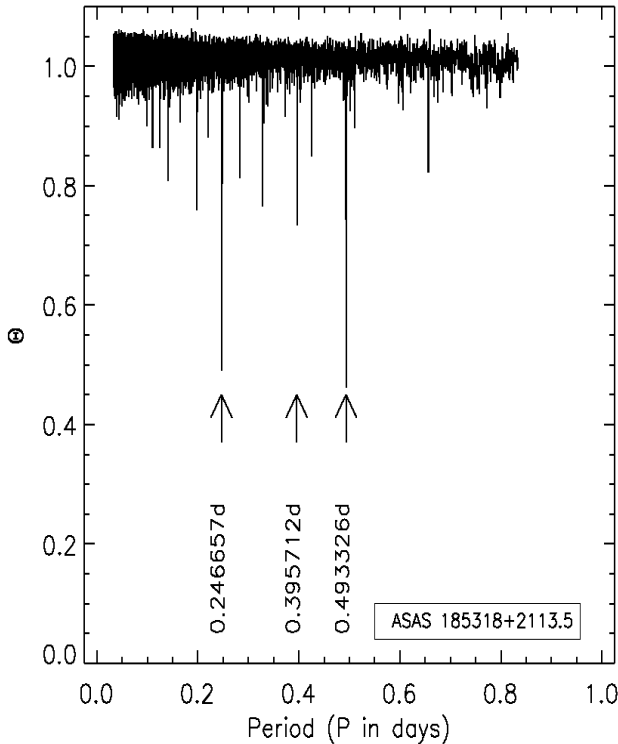


Figure 2. Plot of Θ versus period for ASAS 185318+2113.5 as determined from PDM.

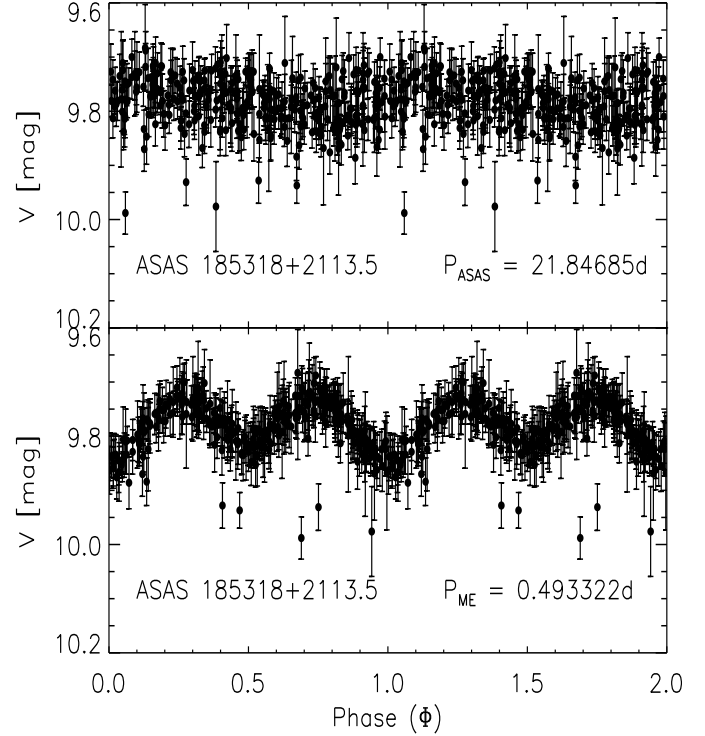


Figure 3. The upper panel shows the phased light curve of ASAS 185318+2113.5 determined from the ASAS period $P_{ASAS} = 21.84685d$. The lower panel shows the phased light curve of the same star with period $P_{ME} = 0.493322d$.

amplitudes of the components and their errors, mass ratios and references for the radial velocity measurements.

4 DETERMINATION OF FOURIER PARAMETERS AND CLASSIFICATION

Rucinski (1993) showed that the light curves of W UMa type systems can be quantitatively described by using only the two coefficients a_2 and a_4 of the cosine decomposition $\sum a_i \cos(2\pi i \Phi)$. The observed light curves were fitted with a Fourier series of the form:

$$m(\Phi) = m_0 + \sum_{i=1}^4 [a_i \cos(2\pi i \Phi) + b_i \sin(2\pi i \Phi)], \quad (3)$$

where $m(\Phi)$ is the phased light curve, m_0 is the mean magnitude and the zero point of the phased light curve corresponds to the primary minimum. Examples of the typical Fourier fits to the ASAS light curves are shown in Fig. 4. The Fourier parameters of the 62 binaries are listed in Table 3. The resulting distribution of the selected sample in the a_2 - a_4 plane is shown in Fig. 5. The continuous envelope for separating the contact binaries from rest of the sample is shown by the relation $a_4 = a_2(0.125 + a_2)$. This is similar to the envelope relation $a_4 = a_2(0.125 - a_2)$ for negative a_2 , a_4 coefficients of Rucinski (1997b). This gives the envelope for the inner contact. The stars lying below this envelope are contact binaries, whereas those lying above it are semi-detached and detached binaries. The stars lying on or above

Table 3. A sample of the Fourier parameters of the ASAS eclipsing binaries used for the analysis. The full table is available as supplementary material in the online version of this paper.

ASAS ID	m_0 σm_0	a_1 σa_1	b_1 σb_1	a_2 σa_2	b_2 σb_2	a_3 σa_3	b_3 σb_3	a_4 σa_4	b_4 σb_4
003628+2132.3	11.10009 0.00248	0.01911 0.00344	-0.00221 0.00359	0.18313 0.00352	-0.00120 0.00356	0.01004 0.00344	-0.00030 0.00365	0.02662 0.00356	0.00128 0.00348
011638-3942.5	10.46070 0.00118	0.01523 0.00170	0.00084 0.00164	0.22563 0.00165	-0.00272 0.00170	0.00552 0.00163	0.00157 0.00172	0.06223 0.00170	-0.00377 0.00165
012104+0736.3	8.65492 0.00181	0.01060 0.00264	-0.00076 0.00249	0.15583 0.00256	0.00097 0.00257	0.00168 0.00261	-0.00065 0.00251	0.02920 0.00252	-0.00353 0.00258
014656-0945.1	11.00120 0.00130	0.10034 0.00192	-0.01179 0.00176	0.22871 0.00185	0.00806 0.00184	0.06391 0.00186	0.00053 0.00181	0.06940 0.00179	-0.00423 0.00188
014854-2053.6	10.53448 0.00104	0.01195 0.00145	-0.00106 0.00149	0.28995 0.00151	-0.00044 0.00143	0.01128 0.00146	-0.00032 0.00148	0.10693 0.00149	0.00190 0.00146
023833-1417.9	9.63591 0.00195	0.00677 0.00273	-0.00058 0.00280	0.25950 0.00274	-0.00234 0.00279	0.00605 0.00281	0.00021 0.00272	0.06771 0.00278	0.00220 0.00275
024952+0856.3	8.80081 0.00205	0.00902 0.00299	-0.00116 0.00283	0.10105 0.00285	0.00172 0.00297	-0.00095 0.00297	0.00050 0.00285	0.01658 0.00300	-0.00235 0.00283
030701-5608.1	11.14192 0.00157	0.11353 0.00225	-0.00113 0.00220	0.23675 0.00221	0.00297 0.00224	0.07194 0.00221	0.00207 0.00225	0.07378 0.00227	0.00289 0.00218

the envelope can be identified by the serial numbers 19, 20, 25, 38, 42, 50 and 56 respectively, corresponding to their ASAS IDs 064558-0017.5, 071058-0352.8, 084108-3212.1, 134607+0506.9, 144803+1356.7, 175332-0354.9 and 203113+0513.2, respectively. Out of these stars, we have identified two stars 084108-3212.1, 203113+0513.2 as detached binaries (ED) and the remaining stars as semi-detached binaries (ESD) following the boundary lines of Derekas et al. (2007). In addition, the star with serial number 37 having ASAS ID 131032-0409.5 is found to be of ESD-type from the light curve modelling although it lies slightly below the envelope. The stars having ASAS IDs 071058-0352.8 and 175332-0354.9 were also found to be of ESD-types by Zola et al. (2004) and Tas & Evren (2006), respectively. In general, the Fourier coefficients a_2 relates to the amplitude, a_1 and a_3 to the difference in the depth of the eclipses and b_1 to the difference between the two maxima (Rucinski 1997a; Paczyński et al. 2006). The phenomenon of difference in the height of the two maxima is called the O'Connell (1951) effect. In Fig. 6, we have plotted the temperature differences (ΔT) obtained from the light curve modelling versus a_1+a_3 for the 62 eclipsing binaries in the present sample. The stars with serial numbers 4, 8, 13, 15, 19 and 53 were found to be binaries having temperature differences of 1000 K or larger between the components obtained from the light curve modelling. However, sometimes the Fourier fit does not reproduce the bottom of the eclipses very well and the algorithm misclassifies the objects. For example, the star having serial number 45 with ASAS ID 155649+2216.0 may be misclassified as a B-type system by the Fourier fitting algorithm because of it gives higher value of a_1 , although, it is not a B-type binary having $\Delta T \sim 316$ K. The classification results of eclipsing binary stars based on the single band photometry using the Fourier coefficients and without any spectroscopic information are generally considered preliminary (Paczynski et al. 2006). It should be noted that the star having serial number 53 with ASAS ID

185318+2113.5 is a B-type contact binary obtained from the light curve modelling, although, it has smaller values of the Fourier coefficients a_1 and a_3 . We have also found that when the sum (a_1+a_3) is normalised by a_2 , the star with serial number 53 moves right on the Fig. 6. This implies that the coefficients a_1 and a_3 are obviously inclination dependent and also, to some extent, on amplitude. It is obvious that the Fourier method has given smaller values of (a_1+a_3) for this very low inclination star. More accurate morphological classification of eclipsing binary stars is usually done from the photometric light curve modelling with the mass ratio q obtained from spectroscopic radial velocity measurements.

5 LIGHT CURVE MODELLING

The mass ratios obtained from radial velocity measurements, mostly by RC, were used with the ASAS photometry to derive the geometrical and physical parameters of the 62 binary stars. For the light curve modelling, we have used the WD code (Wilson & Devinney 1971; Wilson 1979, 1990) as implemented in the software PHOEBE (Prša & Zwitter 2005). In the WD code, some of the parameters need to be fixed and the convergence of the solutions were obtained using the methods of multiple-subsets. In the code, since most of the binaries were the contact binaries, mode-3 version was the most suitable for the light curve analysis. However, at the outset, mode 2 (detached) was used to get the convergence of the solution and then rapidly ran into mode 3 for the final convergence. In the light curve analysis using the WD code, star 1 is the one eclipsed at primary minimum and star 2, at the secondary minimum. This notation has been used throughout the text.

The input parameters to the WD-code are: the mass ratio (q), temperature of the star 1 T_1 , the bolometric albedos $A_1 = A_2 = 0.5$ for stars having convective envelopes ($T < 7200$ K) and 1 for radiative envelopes ($T > 7200$ K)

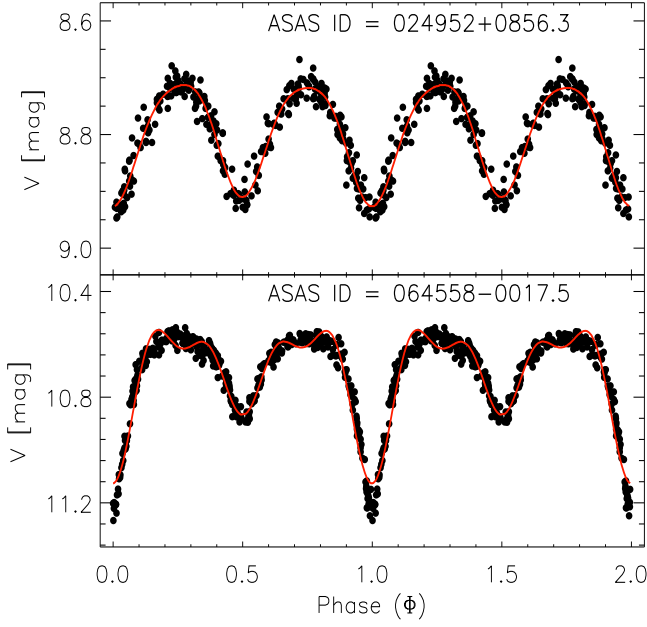


Figure 4. Typical Fourier fits for the ASAS eclipsing binaries used for the analysis.

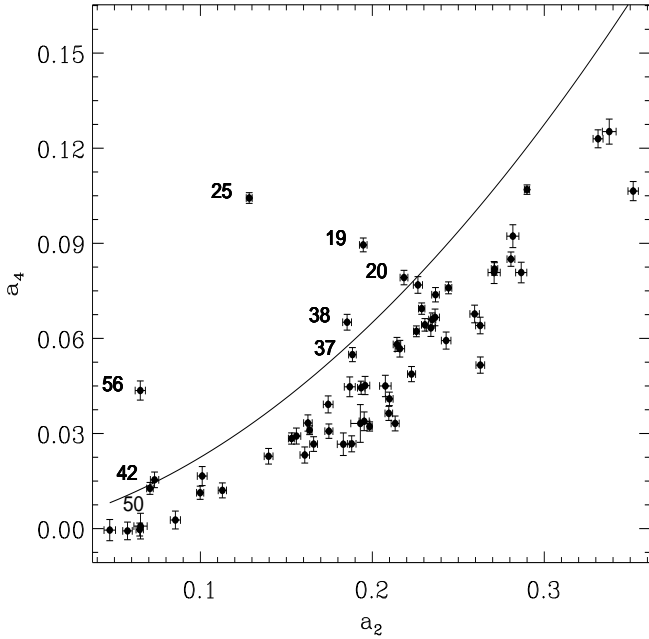


Figure 5. Classification of the 62 eclipsing binaries in the a_2 – a_4 plane of Fourier coefficients. Stars lying below the envelope are contact binaries and those lying above it are semi-detached and detached binaries. The semi-detached and detached binaries in the sample are marked by their serial numbers as in Table 1 corresponding to their respective ASAS IDs and described as in the text.

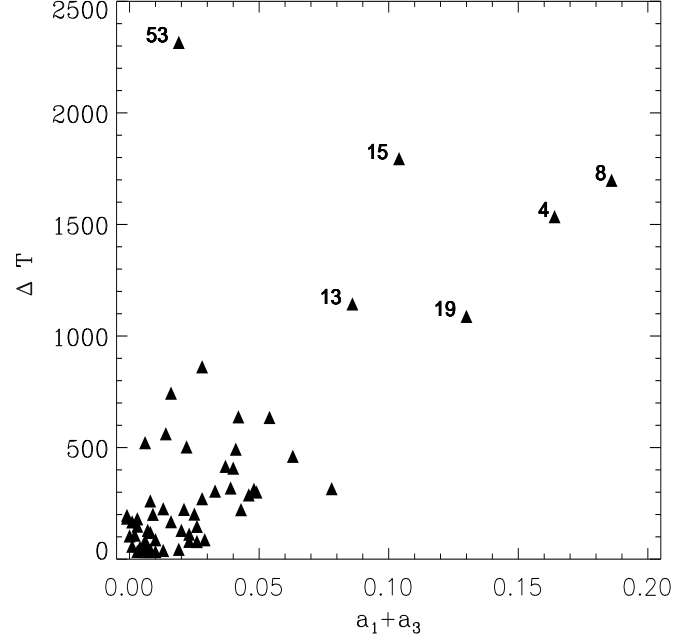


Figure 6. Relation between the Fourier coefficients a_1+a_3 and the temperature difference ($\Delta T \geq 1000$ K) obtained from the modelling for the 62 eclipsing binaries in the sample.

and gravity darkening coefficients $g_1 = g_2 = 0.32$ for convective envelopes and 1.0 for radiative envelopes, following Von Zeipel’s law. The mono-chromatic and bolometric limb darkening coefficients were interpolated for logarithmic law from van Hamme’s table (van Hamme 1993).

The adjustable parameters are the temperature of the star 2, orbital inclination (i), the surface potentials Ω_1 , Ω_2 of the components, monochromatic luminosity of star 1 L_1 . Planck function was used to compute the luminosity of the star 1. In some cases, third light (l_3) was also kept as an adjustable parameter in order to get better fit of some of the light curves. The third light (l_3) is in the unit of total light as implemented in PHOEBE. However, determination of l_3 from the photometric light curve modelling sometimes affects the orbital inclination, amplitude of the light curve. In the two cases (051114–0833.4 and 100141+1724.5), we have found that the determination of third light is highly correlated with the orbital inclination. In these cases, we have chosen l_3 as determined from spectroscopy and available in the literature. The values of l_3 for these two stars were 0.16 ± 0.02 (Pribulla et al. 2009b) and 0.13 (Pribulla et al. 2007), respectively. We have adopted these values of l_3 and kept them fixed in the light curve modelling. In the case of two stars 073246–2047.5 and 204628–7157.0, we found that their light curves could not be fitted properly, especially the minima, using the q_{sp} values. Therefore, we have also kept spectroscopic mass ratio q_{sp} as an adjustable parameter to get a better fit to these light curve data. In these two cases, we have used only the adjusted mass ratios. The values of photometric mass ratio q_{ph} obtained for the two cases are $q_{ph} = 0.190 \pm 0.020$, 0.200 ± 0.013 , whereas, their spectroscopic values were 0.25(3) (Duerbeck & Rucinski 2007), 0.228(8) (Rucinski & Duerbeck 2006), respectively. In the

case of star 073246–2047.5, the q_{ph} value is within 2σ of q_{sp} , whereas for 204628–7157.0, the q_{ph} is within 3.5σ of q_{sp} value, which may be considered a little higher. These values of q_{ph} were used to model these two stars. We have marked the solutions for these two stars in Table 4. For semi-detached binaries, mode 4 and 5 of the WD code were used suitable for the primary and the secondary stars filling their limiting lobes respectively. The fill-out factor (f) is given by

$$f = \frac{\Omega_{in} - \Omega_{1,2}}{\Omega_{in} - \Omega_{out}}, \quad (4)$$

where Ω_{in} and Ω_{out} refer to the inner and the outer Lagrangian surface potentials respectively and $\Omega_{1,2}$ represents the potential of the surface of star 1, 2 respectively. In the case of contact binaries $\Omega_1 = \Omega_2 = \Omega$, where Ω is the surface potential of the common envelope for the binary system. For semi-detached binaries with the primary component filling its Roche lobe, $\Omega_1 = \Omega_{in}$ and with the secondary filling its Roche lobe $\Omega_2 = \Omega_{in}$. For detached binaries $\Omega_{1,2} > \Omega_{in}$. Therefore, the eclipsing binaries are classified into contact, semi-detached and detached binaries according to $0 < f < 1$, $f = 0$ and $f < 0$ respectively. Contact binaries are classified as A-type, if the primary minimum is a transit and W-type, if it is an occultation. Therefore $M_2/M_1 < 1$ for A-type, $M_2/M_1 > 1$ for W-type contact binaries. The surface temperature difference between the two components is in general less than 1000 K. On the other hand, if the temperature difference between the components $\Delta T \geq 1000$ K, then those contact binaries are sometimes called B-type (Csizmadia & Klagyivik 2004). Lucy & Wilson (1979) first introduced B-type systems which are systems in geometrical contact, but not in thermal contact, and therefore, there are large surface temperature differences between the components (Csizmadia & Klagyivik 2004) that produce differences in the levels of the minima. These binaries show an EB (β Lyrae)-type light curve, but have an orbital period which falls in the range of classical W UMa systems (Kaluzny 1986). Rucinski (1997a) defined the B-type contact systems as those systems which show large differences in depths of eclipses, yet appear to be in contact and exhibit β Lyrae-type light curves. Some of them may be very close, semi-detached binaries (ESD) mimicking contact systems and some may be in contact. No attempt has been made to obtain spot parameters for the systems showing O’Connell (1951) effect. As it has been observed that with the spot solutions included in the WD code, the whole light curve can be easily fitted, but a serious problem of uniqueness of the solution persists (Maceroni & van’t Veer 1993) unless other means of investigation such as Doppler Imaging techniques are applied (Maceroni et al. 1994). The stars with serial numbers 15, 34, 43, 48 57 and 60 exhibit typical O’Connell (1951) effect. A reasonable fit to the maxima of the light curves of these stars could be obtained from the light curve modelling without spots. In this paper, the more massive component is denoted by M_P , and the less massive component by M_S . Also, throughout this paper, unless the errors are written otherwise, we express the standard errors in terms of the last quoted digits. For example, 2970.55742(53) should be interpreted as 2970.55742 \pm 0.00053.

The output of the WD’s differential correction (dc) minimization program as implemented in PHOEBE are the val-

ues of the fitting parameters and the formal statistical errors associated with each of the fitting parameters. Sometimes, the error estimates are too optimistic. The values, errors and stability of the solutions were explored using the Monte Carlo parameter scan (heuristic scan) around the best solution using the PHOEBE’s scripter capability (Bonanos 2009). The WD’s dc minimization program was run 1000 times, each time updating the input parameter values to the values determined in the previous iteration. The final values for the parameters were determined from the mean of the parameters obtained in 1000 iterations and the standard deviations were taken as the errors on these parameters. In Fig. 7, we show the histograms of the results obtained using the heuristic scan method for the four parameters fit in the overcontact mode with PHOEBE for the star ASAS 024952+0856.3. For the present sample in this study, we have found that the error estimates of the fitting parameters obtained using the heuristic scan method are reasonable, except for the temperature error σT_2 , which is unrealistically small and underestimated. In order to obtain a realistic estimate of the error in T_2 , we derived the values of T_2 for two fixed values: $T_1 - \sigma T_1$ and $T_1 + \sigma T_1$, keeping other parameters fixed as obtained for T_1 from the modelling, where the value of σT_1 is obtained from the color/spectral type - temperature calibration (Cox 2000) and is listed in Table 4. We then find the temperature differences between the newly obtained values of T_2 in the two cases and the T_2 value obtained for T_1 . The mean value of these two temperature differences is taken as the approximate error in T_2 .

Fig. 8 shows the phased light curves of all the 62 stars in the present study. Solid line is the synthetic light curve computed from the WD light curve modelling technique.

5.1 Temperatures

To determine the effective temperatures of the primary components of the program stars, we used the spectral types of these stars from the literature, mostly from RC. Then, theoretical spectral type-temperature relations (Cox 2000) were used to calculate the temperatures of the primary components. However, when the spectral type is not given in the literature, we used the $(J-K)$ color index from 2MASS catalogue (Cutri et al. 2003) to determine its spectral type using color-temperature calibration of Cox (2000). For majority of stars in the sample, the spectral types were determined by RC either by direct spectral classification or using $(B-V)$ or $(J-K)$ color index. 2MASS data are very useful for spectral classification on the basis of the observed colors, especially the $(J-K)$ color, with the advantage that the effect of interstellar reddening is negligible compared to $(B-V)$ and is monotonically rising from the early spectral types to about M0V (Cox 2000; Pribulla et al. 2009b). The temperatures of the secondary components were estimated by using PHOEBE with the temperatures of the primaries fixed. For one star in the sample 110505+0509.1 (Ap Leo), we have not found any spectral classification. In that case, we estimated its spectral type to be F8V corresponding to its infrared color index $(J-K) = 0.368$ mag. On the other hand, when the spectral classification in RC is given as F5/8V, we take its spectral class as F8V.

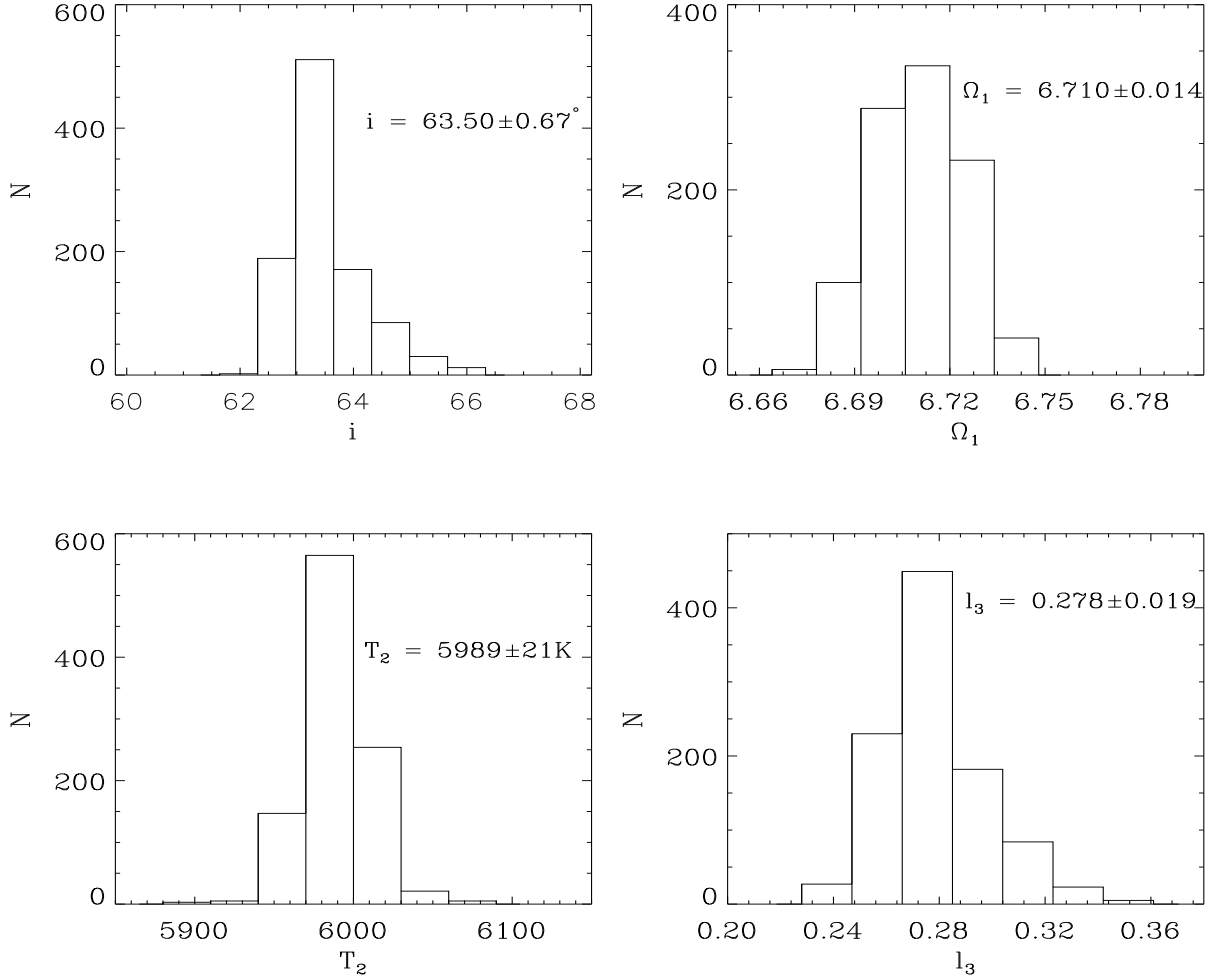


Figure 7. Histograms of the results obtained using the Monte Carlo parameter scan for the four parameters fit in the overcontact mode with PHOEBE for the star ASAS 024952+0856.3.

5.2 Absolute dimensions

In order to calculate the absolute dimensions of the eclipsing binary systems, we used the orbital elements obtained from the spectroscopy as given in the literature. The orbital elements are the velocity semi-amplitudes (K_1, K_2). From the light curve modelling, we found orbital inclination i , temperatures of the secondary components T_2 , fractional stellar radii r_1, r_2 . The radii $r_{1,2}$ obtained from the light curve modelling are normalised to the semi-major axis of the binary system, i.e., $r = R/a$, where a is the semi-major axis and is determined using i, K_1, K_2, P . Period P is that obtained from the ME method. The component radii were taken as the geometrical mean of the polar, side and back radii for contact systems and polar, side, back and point radii for semi-detached and detached systems. The luminosities of the two components were calculated from the radii and temperatures by $L_j/L_\odot = (R_j/R_\odot)^2 (T_j/5780)^4$, where suffix j refer to either component of the system. The mass function of the system is defined as $f(M) = (M_1 + M_2) \sin^3(i)$, where total mass of the system $M = (M_1 + M_2)$ in solar unit (M_\odot)

was obtained using the Kepler's third law. Hence the individual masses were obtained using the total mass and the mass ratio. The spectroscopic estimate of mass function is given by (Rucinski & Lu 1999):

$$f(M) = 1.0385 \times 10^{-7} (K_1 + K_2)^3 P(\text{days}) [M_\odot]. \quad (5)$$

6 RESULTS AND COMPARISON WITH THE LITERATURE

In this section, we present determinations of the geometrical and physical parameters of the 62 eclipsing binary stars using the WD code and the orbital elements as given in the literature. Table 4 lists the parameters obtained from the light curve modelling. In Table 5, we list the physical parameters of all the 62 stars determined using the parameters in Table 4 and the radial velocity semi-amplitudes as listed in Table 2.

Table 4. Results obtained from the light curve modelling

ASAS ID	$i[^\circ]$	Ω_1	Ω_2	x_1	x_2	r_1	r_2	T_1 [K]*	T_2 [K]	fill-out	l_3
003628+2132.3	79.88± 1.72	1.985± 0.010	1.985	0.72	0.72	0.587± 0.007	0.268± 0.006	6381±182	6294±172	0.85	0
011638-3942.5	74.00± 0.22	6.096± 0.008	6.096	0.73	0.73	0.307± 0.001	0.479± 0.001	5940±149	5717±138	0.19	0
012104+0736.3	69.06± 0.80	2.253± 0.012	2.253	0.73	0.73	0.525± 0.004	0.274± 0.005	6250±157	6024±150	0.35	0
014656-0945.1	82.25± 0.44	2.676± 0.006	2.676	0.70	0.79	0.464± 0.001	0.310± 0.002	6765±153	5230± 93	0.08	0
014854-2053.6	81.18± 0.10	3.308± 0.002	3.308	0.73	0.73	0.357± 0.001	0.408± 0.001	5865±152	5753±147	0.06	0
023833-1417.9	82.48± 0.34	2.529± 0.005	2.529	0.71	0.71	0.486± 0.001	0.308± 0.002	6650±178	6611±176	0.24	0
024952+0856.3	63.50± 0.67	6.710± 0.014	6.710	0.73	0.73	0.293± 0.001	0.494± 0.001	6250±237	5989±220	0.02	0.278±0.019
030701-5608.1	80.36± 0.17	2.778± 0.006	2.778	0.70	0.79	0.455± 0.001	0.323± 0.001	6881±169	5183± 99	0.18	0
030953-0653.6	75.70± 0.23	6.065± 0.008	6.065	0.74	0.74	0.308± 0.001	0.479± 0.001	6093±153	6006±150	0.18	0
033459+1742.6	68.10± 0.24	7.251± 0.011	7.251	0.73	0.73	0.284± 0.001	0.503± 0.001	5940±259	5906±254	0.18	0.013±0.009
034814+2218.9	82.33± 0.46	2.711± 0.006	2.711	0.73	0.73	0.464± 0.001	0.322± 0.002	5790±128	5711±119	0.09	0
034928+1254.7	74.50± 0.69	5.057± 0.007	5.057	0.73	0.73	0.326± 0.001	0.436± 0.001	6250±126	6082±119	0.03	0
035153-1031.8	74.50± 0.69	2.406± 0.023	2.406	0.70	0.76	0.504± 0.007	0.298± 0.008	6881±177	5737±122	0.37	0
041209-1028.2	80.44± 0.23	5.547± 0.008	5.547	0.73	0.73	0.318± 0.001	0.461± 0.001	5712±145	5411±129	0.16	0
042925-3334.6	69.40± 0.25	2.337± 0.004	2.337	0.70	0.80	0.525± 0.002	0.326± 0.002	6881±196	5086±104	0.71	0
051114-0833.4	82.08± 0.44	4.430± 0.029	4.430	0.72	0.74	0.360± 0.004	0.433± 0.004	6250±153	5931±134	0.25	0.16 ± 0.02 ^a
051832-6813.6	76.32± 0.15	4.556± 0.013	4.556	0.73	0.73	0.351± 0.002	0.432± 0.002	5560±116	5272±103	0.20	0
062605+2759.9	76.28± 0.90	2.081± 0.007	2.081	0.72	0.72	0.563± 0.003	0.271± 0.004	6381±134	6416±135	0.66	0
064558-0017.5	89.00± 2.60	3.190	3.343 ± 0.052	0.72	0.80	0.442± 0.002	0.327± 0.010	6250±157	5162±109	0.00	0.242±0.027
071058-0352.8	74.85± 0.07	4.037± 0.011	3.701	0.71	0.72	0.342± 0.002	0.402± 0.002	7640±174	7744±182	0.00	0
073246-2047.5	84.47± 0.58	2.121± 0.002	2.121	0.70	0.70	0.557± 0.001	0.284± 0.001	6881±315	6801±304	0.71	0 [†]
073338-5007.4	79.47± 0.73	2.134± 0.004	2.134	0.71	0.71	0.553± 0.002	0.278± 0.002	6514±144	6662±148	0.57	0
073905-0239.1	72.14± 0.27	2.512± 0.005	2.512	0.70	0.70	0.496± 0.002	0.329± 0.002	7000±191	6584±169	0.49	0
084002+1900.0	62.19± 0.48	5.427± 0.021	5.427	0.73	0.73	0.323± 0.003	0.460± 0.002	6250±127	6121±120	0.23	0
084108-3212.1	90.10± 0.97	6.004± 0.056	6.640 ± 0.095	0.67	0.67	0.200± 0.002	0.172± 0.002	7468±203	7521±208	< 0	0
100141+1724.5	68.63± 0.37	4.214± 0.022	4.214	0.75	0.75	0.368± 0.003	0.423± 0.003	5150±118	4742±248	0.25	0.13 ^b
100234+1702.8	77.16± 0.42	2.471± 0.010	2.471	0.69	0.69	0.500± 0.003	0.321± 0.004	7300±170	7265±167	0.40	0
100248+0105.7	79.12± 0.44	2.146± 0.009	2.146	0.70	0.72	0.550± 0.003	0.279± 0.005	6650±163	6448±153	0.52	0.114±0.011
101602-0618.5	74.88± 0.65	1.928± 0.002	1.928	0.70	0.72	0.594± 0.001	0.221± 0.001	6881±199	6378±169	0.42	0
104033+1334.0	84.05± 0.89	2.374± 0.004	2.374	0.69	0.69	0.514± 0.002	0.313± 0.002	7148±163	7158±167	0.83	0
105030-0241.7	65.53± 0.18	6.720± 0.007	6.720	0.73	0.73	0.294± 0.001	0.493± 0.001	5960±182	5877±176	0.20	0
110211+0953.7	73.85± 0.15	5.400± 0.006	5.400	0.70	0.70	0.324± 0.001	0.460± 0.001	6650±148	6616±144	0.18	0
110505+0509.1	79.66± 0.65	2.404± 0.012	2.404	0.73	0.73	0.503± 0.004	0.295± 0.004	6250±155	6247±156	0.37	0
120103+1300.5	72.54± 0.30	2.547± 0.006	2.547	0.70	0.70	0.489± 0.002	0.324± 0.002	8180±188	7542±167	0.40	0
121206+2232.0	90.58± 2.85	4.982± 0.027	4.982	0.79	0.79	0.338± 0.004	0.450± 0.003	4546± 72	4399± 67	0.04	0
123300+2642.9	72.43± 0.29	5.319± 0.009	5.319	0.77	0.77	0.326± 0.001	0.457± 0.001	4830±115	4517± 98	0.15	0
131032-0409.5	68.91± 0.22	4.231± 0.019	4.207	0.77	0.77	0.382± 0.003	0.428± 0.001	4830±136	4559±121	0.00	0
134607+0506.9	79.06± 0.43	3.437	4.998 ± 0.077	0.73	0.73	0.356± 0.002	0.360± 0.001	6250±145	6211±146	0.00	0
141726+1234.1	77.29± 0.39	2.698± 0.014	2.698	0.73	0.73	0.463± 0.003	0.316± 0.004	5560±120	5099±101	0.12	0
141937+0553.8	65.52± 0.43	2.696± 0.017	2.696	0.69	0.69	0.482± 0.005	0.362± 0.006	7148±198	7201±203	0.60	0
143504+0906.8	60.87± 0.89	1.924± 0.004	1.924	0.73	0.73	0.601± 0.001	0.255± 0.004	6250±219	6234±216	0.91	0
144803+1356.7	73.96± 1.00	2.348	2.978 ± 0.086	0.70	0.70	0.535± 0.002	0.157± 0.009	6650±175	6846±187	0.00	0.302±0.036
152243+1615.7	50.47± 2.24	2.090± 0.017	2.090	0.73	0.73	0.552± 0.005	0.260± 0.006	5940±144	5759±283	0.68	0
153152-1541.1	90.35± 2.40	2.479± 0.007	2.479	0.73	0.73	0.492± 0.002	0.302± 0.002	5790±162	5974±166	0.29	0.207±0.008
155649+2216.0	83.85± 0.67	3.157± 0.058	3.157	0.73	0.73	0.446± 0.007	0.349± 0.007	5636±108	5320± 92	0.46	0
164121+0030.4	69.77± 0.21	6.397± 0.013	6.397	0.73	0.73	0.307± 0.002	0.495± 0.001	5940±136	5739±129	0.22	0
165717+1059.8	47.05± 0.68	2.261± 0.007	2.261	0.73	0.73	0.525± 0.002	0.267± 0.001	5560±135	5440±127	0.21	0
171358+1621.0	88.69± 5.29	2.374± 0.029	2.374	0.70	0.74	0.506± 0.009	0.286± 0.001	6765±168	6130±139	0.30	0
173356+0810.0	44.06± 1.24	5.954± 0.027	5.954	0.73	0.73	0.303± 0.003	0.465± 0.003	5940±165	5418±332	0.14	0
175332-0354.9	57.97± 0.31	2.505± 0.007	2.446	0.73	0.73	0.491± 0.003	0.299± 0.001	5940±151	5773±144	0.00	0.144±0.008
180921+0909.1	80.19± 0.25	2.363± 0.003	2.363	0.71	0.71	0.518± 0.001	0.320± 0.001	6381±135	6424±136	0.61	0
182913+0647.3	66.36± 0.48	6.991± 0.023	6.991	0.72	0.72	0.301± 0.003	0.514± 0.002	6381±191	6273±180	0.56	0
185318+2113.5	41.59± 2.78	2.569± 0.034	2.569	0.72	0.80	0.481± 0.009	0.311± 0.010	7816±173	5500±623	0.41	0
193524+0550.3	82.47± 0.22	6.160± 0.005	6.160	0.72	0.72	0.307± 0.001	0.483± 0.001	6381±153	6252±147	0.24	0
194813+0918.5	93.81± 0.22	3.384± 0.006	3.384	0.74	0.75	0.413± 0.001	0.384± 0.001	6093±152	5871±140	0.24	0
203113+0513.2	77.06± 1.76	6.017± 0.591	4.384 ± 0.094	0.77	0.77	0.200± 0.021	0.281± 0.008	4830± 94	4337± 68	< 0	0
204628-7157.0	84.81± 0.60	2.147± 0.003	2.147	0.70	0.70	0.552± 0.001	0.287± 0.002	6881±160	6837±158	0.52	0.089±0.005 [†]
205710+1939.0	45.25± 2.45	6.051± 0.080	6.051	0.73	0.75	0.308± 0.009	0.478± 0.008	6250±185	6192±168	0.09	0
222257+1619.4	87.96± 2.59	6.142± 0.012	6.142	0.72	0.74	0.311± 0.001	0.487± 0.002	6381±126	6076±113	0.32	0
233655+1548.1	71.11± 0.67	2.240± 0.009	2.240	0.70	0.71	0.470± 0.003	0.312± 0.003	7300±184	6438±141	0.81	0
234535+2528.3	73.23± 0.33	2.640± 0.012	2.640	0.69	0.69	0.541± 0.003	0.319± 0.006	7000±192	6438±161	0.10	0
234718-0805.2	70.36± 0.32	2.177± 0.004	2.177	0.70	0.70	0.542± 0.002	0.276± 0.002	6881±182	6137±140	0.48	0

*The errors in T_1 are obtained from the color/spectral type-temperature calibration (Cox 2000) and are not obtained from the modelling. [†]The solutions are obtained using the q_{ph} values as described in the text. ^aPribulla et al. (2009b), ^bPribulla et al. (2007).

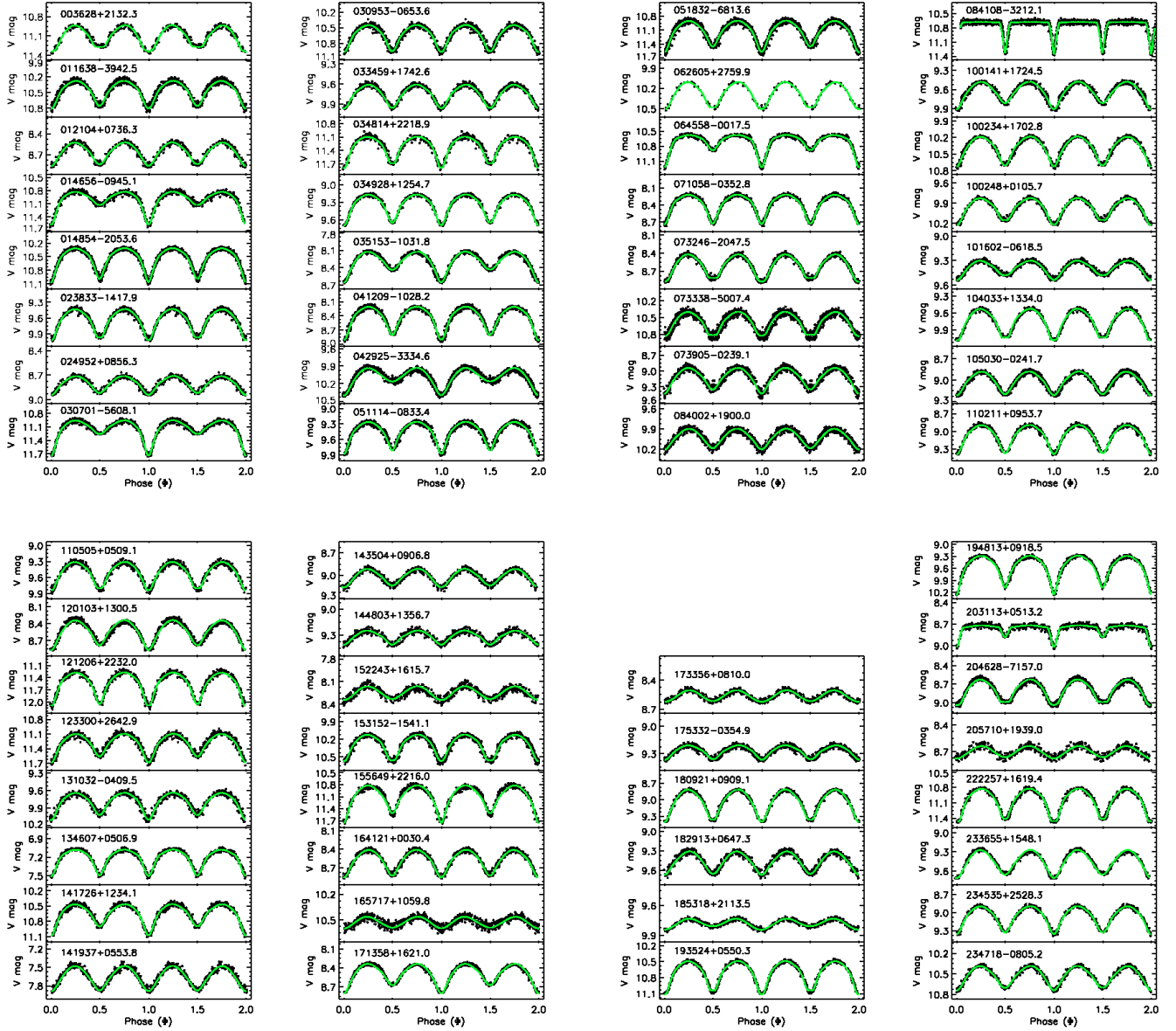


Figure 8. Phased light curves of all the 62 stars in the present study. Solid line is the synthetic light curve computed from the WD light curve modelling technique. The parameters obtained from the modelling are listed in Table 4.

6.1 Comparison with 203113+0513.2 = MR Del

In order to check the quality of the results obtained, we compare the spectral type of the system MR Del (203113+0513.2) as given in Pribulla et al. (2009b) to that determined by us from the light curve modelling. Pribulla et al. (2009b) predicted a spectral classification (K2V+K6V) for the system. Spectral type K2V is consistent with the infrared color index of $(J - K) = 0.620$ mag. Assuming this as the spectral type of the primary component, we calculated its temperature as $T_1 = 4830$ K following the calibration of Cox (2000). From the light curve modelling, we found the temperature of the secondary component as $T_2 = 4337 \pm 68$ K, which is consistent with the spectral type K6V for the secondary component as estimated by Pribulla et al. (2009b).

We also compare the determination of physical parameters of 23 stars common to our sample with the previous recent publications. We list all the 23 stars in Table 6 and their physical parameters along with the references in the literature. In Fig. 9, we show scatter plots between the parameters determined by us (shown on the X-axis and represented by 'DS' in the parenthesis) and those in the literature (shown on the Y-axis and represented by 'Lit' in the parenthesis). From Fig. 9, it seems that the errors in L_1 and L_2 were underestimated in some of the cases in the literature and their calculations were not clearly mentioned. The clustering of data points along a straight line of zero intercept and unit slope indicates a positive linear correlation with the presence of three outliers. The ASAS IDs of these stars are 024952+0856.3 (EE Cet), 071058-0352.8 (V753 Mon),

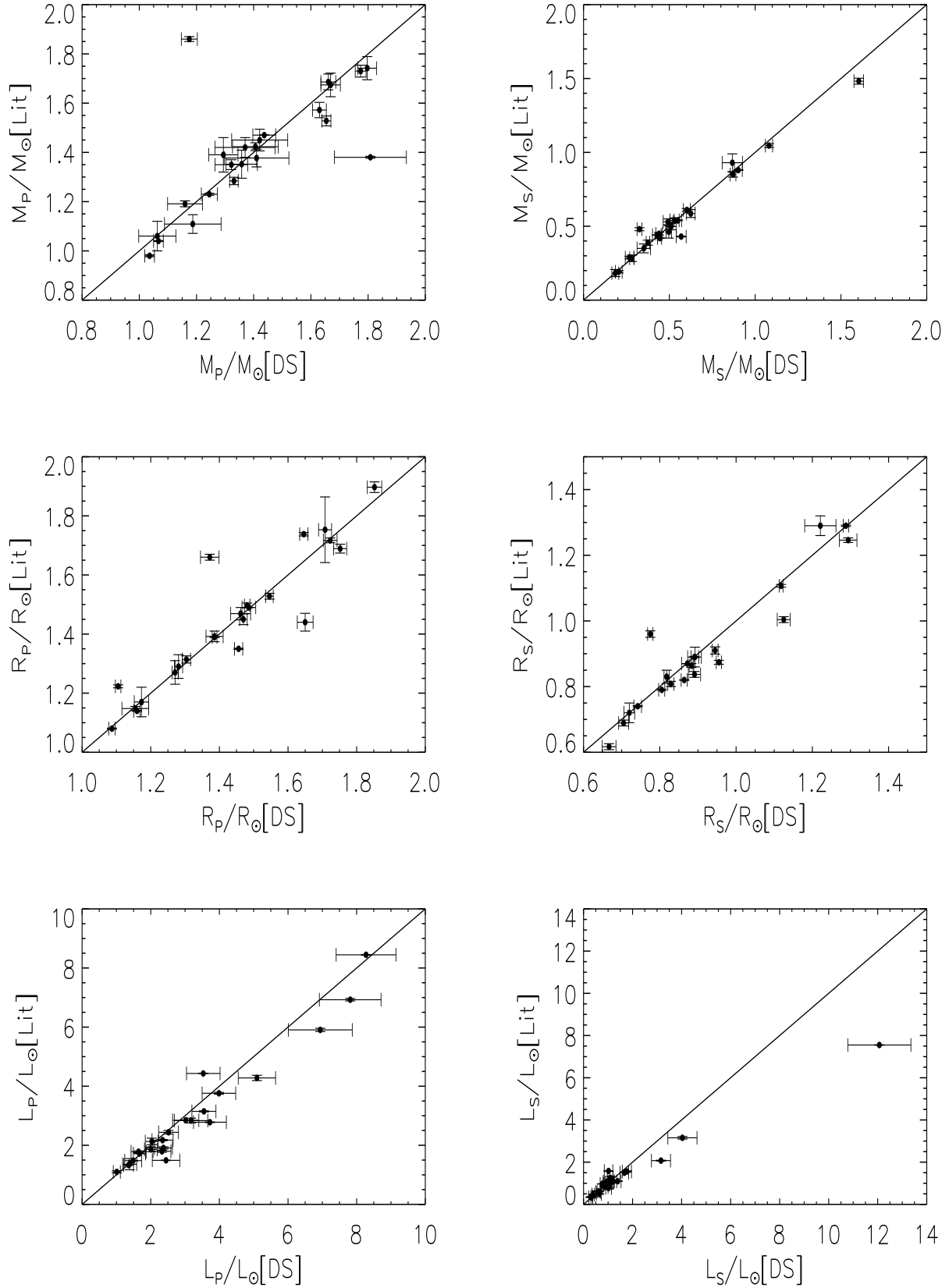


Figure 9. The comparison of primary and secondary component parameters of 23 stars in our sample common to literature. The parameters determined by us are plotted on the X-axis while those in the literature, on the Y-axis. The clustering of most of the data points along a line (solid) indicates a positive linear correlation.

Table 5. Physical parameters of the 62 eclipsing binary stars

ID	a [in R_\odot]	M/M_\odot	$f(M)$ [in M_\odot]	M_1/M_\odot	M_2/M_\odot	R_1/R_\odot	R_2/R_\odot	L_1/L_\odot	L_2/L_\odot
003628+2132.3	2.490± 0.039	1.542± 0.070	1.471± 0.071	1.358± 0.055	0.185± 0.020	1.462± 0.029	0.667± 0.018	3.174± 0.487	0.626± 0.103
011638-3942.5	2.592± 0.027	1.616± 0.049	1.435± 0.044	0.436± 0.041	1.179± 0.151	0.796± 0.009	1.242± 0.013	0.706± 0.086	1.476± 0.174
012104+0736.3	3.253± 0.026	2.037± 0.048	1.659± 0.047	1.661± 0.026	0.375± 0.010	1.708± 0.019	0.891± 0.018	3.987± 0.489	0.937± 0.131
014656-0945.1	3.726± 0.280	2.932± 0.644	2.852± 0.627	2.109± 0.264	0.823± 0.215	1.729± 0.130	1.155± 0.087	5.608± 1.352	0.894± 0.199
014854-2053.6	2.329± 0.032	1.685± 0.067	1.625± 0.065	0.722± 0.053	0.963± 0.097	0.831± 0.012	0.950± 0.013	0.733± 0.097	0.886± 0.115
023833-1417.9	3.046± 0.027	1.948± 0.051	1.898± 0.050	1.436± 0.034	0.511± 0.025	1.480± 0.014	0.938± 0.010	3.840± 0.482	1.507± 0.194
024952+0856.3	2.948± 0.024	2.377± 0.056	1.704± 0.050	0.569± 0.029	1.808± 0.126	0.864± 0.008	1.456± 0.012	1.020± 0.173	2.445± 0.400
030701-5608.1	4.277± 0.189	2.680± 0.345	2.568± 0.330	1.823± 0.159	0.857± 0.147	1.946± 0.086	1.381± 0.061	7.605± 1.419	1.234± 0.203
030953-0653.6	3.069± 0.022	1.952± 0.041	1.776± 0.038	0.530± 0.027	1.421± 0.098	0.945± 0.008	1.470± 0.011	1.103± 0.128	2.519± 0.290
033459+1742.6	2.779± 0.011	1.796± 0.021	1.435± 0.018	0.392± 0.015	1.404± 0.070	0.789± 0.004	1.398± 0.006	0.695± 0.129	2.130± 0.385
034814+2218.9	2.500± 0.019	1.795± 0.041	1.747± 0.040	1.245± 0.028	0.550± 0.021	1.160± 0.009	0.805± 0.008	1.355± 0.142	0.618± 0.064
034928+1254.7	2.349± 0.014	1.862± 0.032	1.666± 0.033	0.648± 0.021	1.214± 0.054	0.766± 0.005	1.024± 0.006	0.802± 0.075	1.286± 0.117
035153-1031.8	2.990± 0.108	1.388± 0.146	1.242± 0.132	1.068± 0.123	0.320± 0.057	1.507± 0.058	0.891± 0.040	4.561± 0.822	0.770± 0.135
041209-1028.2	2.257± 0.022	1.489± 0.043	1.428± 0.041	0.426± 0.036	1.063± 0.115	0.718± 0.007	1.041± 0.010	0.491± 0.060	0.832± 0.096
042925-3334.6	3.987± 0.674	2.110± 1.041	1.730± 0.854	1.623± 0.577	0.487± 0.320	2.093± 0.354	1.300± 0.220	8.801± 3.978	1.013± 0.425
051114-0833.4	3.159± 0.028	2.354± 0.061	2.288± 0.060	0.933± 0.034	1.422± 0.078	1.137± 0.016	1.368± 0.018	1.768± 0.223	2.074± 0.241
051832-6813.6	2.020± 0.034	1.354± 0.066	1.242± 0.061	0.523± 0.063	0.830± 0.128	0.709± 0.013	0.873± 0.015	0.430± 0.051	0.527± 0.059
062605+2759.9	3.289± 0.033	1.951± 0.057	1.789± 0.056	1.669± 0.034	0.282± 0.013	1.852± 0.021	0.891± 0.016	5.094± 0.544	1.206± 0.145
064558-0017.5	3.734± 0.050	2.160± 0.084	2.159± 0.084	1.294± 0.051	0.867± 0.059	1.650± 0.023	1.221± 0.041	3.724± 0.479	0.949± 0.143
071058-0352.8	4.814± 0.019	3.258± 0.038	2.930± 0.034	1.654± 0.016	1.604± 0.028	1.646± 0.012	1.935± 0.012	8.274± 0.871	12.067± 1.288
073246-2047.5	4.396± 0.266	1.694± 0.300	1.671± 0.296	1.422± 0.205	0.272± 0.079	2.448± 0.148	1.248± 0.076	12.041± 3.665	2.987± 0.897
073338-5007.4	2.746± 0.201	1.482± 0.317	1.408± 0.301	1.245± 0.270	0.237± 0.125	1.519± 0.111	0.763± 0.056	3.721± 0.875	1.029± 0.243
073905-0239.1	4.453± 0.039	2.907± 0.074	2.507± 0.065	2.117± 0.032	0.790± 0.029	2.209± 0.021	1.465± 0.016	10.494± 1.347	3.614± 0.448
084002+1900.0	2.762± 0.016	1.924± 0.033	1.331± 0.029	0.602± 0.020	1.322± 0.057	0.892± 0.010	1.271± 0.009	1.088± 0.112	2.030± 0.189
084108-3212.1	11.791± 0.119	4.083± 0.120	4.083± 0.120	2.078± 0.040	2.005± 0.079	2.358± 0.033	2.028± 0.031	15.499± 2.125	11.792± 1.667
100141+1724.5	2.071± 0.011	1.473± 0.022	1.190± 0.020	0.621± 0.020	0.852± 0.035	0.762± 0.007	0.876± 0.008	0.366± 0.041	0.348± 0.079
100234+1702.8	3.505± 0.032	2.422± 0.064	2.245± 0.061	1.797± 0.033	0.625± 0.025	1.752± 0.019	1.125± 0.017	7.813± 0.898	3.159± 0.388
100248+0105.7	2.850± 0.031	1.758± 0.056	1.665± 0.054	1.471± 0.040	0.287± 0.020	1.568± 0.019	0.795± 0.017	4.305± 0.528	0.979± 0.134
101602-0618.5	3.148± 0.021	1.431± 0.028	1.288± 0.028	1.301± 0.022	0.130± 0.006	1.870± 0.013	0.696± 0.006	7.021± 0.909	0.717± 0.088
104033+1334.0	4.412± 0.028	2.619± 0.051	2.577± 0.051	2.010± 0.024	0.609± 0.017	2.165± 0.017	1.318± 0.012	10.964± 1.168	4.089± 0.457
105030-0241.7	3.004± 0.016	1.846± 0.029	1.392± 0.022	0.440± 0.019	1.406± 0.080	0.883± 0.006	1.481± 0.008	0.882± 0.119	2.345± 0.308
110211+0953.7	2.770± 0.012	2.126± 0.026	1.884± 0.024	0.669± 0.016	1.457± 0.048	0.897± 0.005	1.274± 0.006	1.411± 0.140	2.787± 0.269
110505+0509.1	2.954± 0.033	1.864± 0.060	1.775± 0.058	1.437± 0.040	0.427± 0.025	1.486± 0.020	0.872± 0.015	3.019± 0.382	1.037± 0.140
120103+1300.5	4.501± 0.031	2.956± 0.059	2.566± 0.053	2.139± 0.024	0.817± 0.021	2.201± 0.018	1.458± 0.013	19.432± 2.096	6.165± 0.660
121206+2232.0	1.580± 0.008	1.085± 0.015	1.084± 0.015	0.374± 0.018	0.710± 0.043	0.534± 0.007	0.711± 0.006	0.109± 0.010	0.170± 0.013
123300+2642.9	1.723± 0.009	1.216± 0.019	1.053± 0.017	0.389± 0.020	0.826± 0.054	0.562± 0.004	0.787± 0.005	0.154± 0.017	0.231± 0.023
131032-0409.5	2.313± 0.008	1.710± 0.017	1.389± 0.015	0.745± 0.013	0.964± 0.023	0.883± 0.008	0.990± 0.004	0.381± 0.049	0.379± 0.043
134607+0506.9	3.105± 0.012	2.412± 0.028	2.283± 0.029	1.331± 0.015	1.081± 0.021	1.105± 0.008	1.118± 0.005	1.671± 0.178	1.666± 0.173
141726+1234.1	2.348± 0.011	1.479± 0.020	1.373± 0.020	1.036± 0.017	0.443± 0.012	1.087± 0.009	0.742± 0.010	1.012± 0.103	0.333± 0.035
141937+0553.8	3.574± 0.019	2.645± 0.042	1.994± 0.037	1.774± 0.019	0.871± 0.017	1.723± 0.020	1.294± 0.023	6.941± 0.931	4.033± 0.595
143504+0906.8	2.550± 0.026	1.760± 0.053	1.173± 0.047	1.584± 0.034	0.176± 0.008	1.533± 0.016	0.650± 0.012	3.211± 0.518	0.572± 0.101
144803+1356.7	2.754± 0.026	1.633± 0.044	1.450± 0.045	1.309± 0.033	0.325± 0.017	1.473± 0.015	0.432± 0.025	3.804± 0.477	0.368± 0.083
152243+1615.7	2.093± 0.068	1.393± 0.132	0.639± 0.087	1.187± 0.099	0.205± 0.020	1.155± 0.039	0.544± 0.022	1.488± 0.245	0.292± 0.081
153152-1541.1	2.384± 0.042	1.414± 0.073	1.413± 0.073	1.063± 0.065	0.351± 0.039	1.173± 0.021	0.720± 0.014	1.385± 0.205	0.592± 0.088
155649+2216.0	2.572± 0.015	1.526± 0.026	1.499± 0.026	0.893± 0.022	0.633± 0.023	1.147± 0.019	0.898± 0.019	1.190± 0.131	0.578± 0.064
164121+0030.4	3.150± 0.014	2.035± 0.027	1.681± 0.023	0.511± 0.017	1.524± 0.071	0.967± 0.008	1.559± 0.008	1.043± 0.112	2.362± 0.236
165717+1059.8	2.641± 0.047	1.428± 0.075	0.560± 0.035	1.160± 0.061	0.268± 0.025	1.386± 0.025	0.705± 0.013	1.646± 0.220	0.390± 0.051
171358+1621.0	2.711± 0.022	1.501± 0.035	1.500± 0.037	1.175± 0.028	0.326± 0.014	1.372± 0.027	0.775± 0.007	3.531± 0.489	0.760± 0.082
173356+0810.0	2.695± 0.061	1.448± 0.096	0.487± 0.046	0.410± 0.071	1.038± 0.192	0.817± 0.020	1.253± 0.030	0.744± 0.120	1.212± 0.355
175332-0354.9	3.181± 0.031	2.368± 0.067	1.443± 0.044	1.834± 0.036	0.534± 0.026	1.562± 0.018	0.951± 0.010	2.720± 0.339	0.900± 0.108
180921+0909.1	2.984± 0.020	2.127± 0.041	2.035± 0.040	1.630± 0.024	0.497± 0.016	1.546± 0.011	0.955± 0.007	3.550± 0.350	1.392± 0.138
182913+0647.3	2.598± 0.013	1.666± 0.025	1.281± 0.024	0.370± 0.017	1.295± 0.073	0.782± 0.009	1.335± 0.009	0.908± 0.129	2.473± 0.315
185318+2113.5	3.470± 0.191	2.299± 0.369	0.672± 0.154	1.675± 0.169	0.625± 0.073	1.669± 0.097	1.079± 0.069	9.317± 1.907	0.955± 0.554
193524+0550.3	2.699± 0.023	1.920± 0.048	1.871± 0.047	0.510± 0.031	1.410± 0.113	0.829± 0.008	1.304± 0.012	1.020± 0.117	2.327± 0.260
194813+0918.5	3.355± 0.015	1.969± 0.025	1.956± 0.025	1.067± 0.017	0.902± 0.023	1.386± 0.007	1.288± 0.007	2.371± 0.260	1.767± 0.187
203113+0513.2	3.009± 0.029	1.340± 0.037	1.240± 0.043	0.700± 0.034	0.640± 0.040	0.602± 0.063	0.845± 0.025	0.177± 0.051	0.227± 0.028
204628-7157.0	4.450± 0.059	1.866± 0.072	1.843± 0.071	1.520± 0.045	0.346± 0.019	2.456± 0.033	1.277± 0.019	12.118± 1.449	3.193± 0.390
205710+1939.0	2.573± 0.112	1.723± 0.220	0.617± 0.111	0.470± 0.138	1.253± 0.401	0.792± 0.042	1.230± 0.058	0.933± 0.206	1.992± 0.403
222257+1619.4	2.630± 0.021	1.863± 0.044	1.860± 0.045	0.493± 0.029	1.370± 0.105	0.818± 0.007	1.281± 0.012	0.915± 0.090	2.003± 0.185
233655+1548.1	4.182± 0.027	2.413± 0.046	2.044± 0.046	1.922± 0.023	0.492± 0.015	1.965± 0.018	1.305± 0.015	9.828± 1.170	2.620± 0.290
234535+2528.3	3.920± 0.016	2.409± 0.029	2.115± 0.028	1.720± 0.015	0.690± 0.013	2.120± 0.015	1.250± 0.024	9.673± 1.195	2.406± 0.333
234718-0805.2	3.254± 0.065	1.990± 0.117	1.663± 0.098	1.655± 0.070	0.336± 0.034	1.764± 0.036	0.898± 0.019	6.248± 0.917	1.025± 0.137

and 171358+1621.0 (AK Her). We discuss these stars in the following subsections in view of mismatch in their parameter determinations.

6.2 ASAS 024952+0856.3 = EE Cet

Variability of the combined light of the visual binary ADS 2163 was discovered by the Hipparcos satellite mission (Perryman & ESA 1997). The system shows a light-curve variation with an amplitude of 0.23 mag and a

Table 6. Physical parameters of 23 stars common to our sample as found in the literature

ID	M_P/M_\odot	M_S/M_\odot	R_P/R_\odot	R_S/R_\odot	L_P/L_\odot	L_S/L_\odot	References
003628+2132.3	1.352± 0.057	0.183± 0.024	1.469± 0.021	0.617± 0.009	2.836± 0.081	0.493± 0.022	Gazeas et al. (2005)
012104+0736.3	1.682± 0.032	0.389± 0.017	1.753± 0.111	0.890± 0.002	3.760± 0.032	0.984± 0.008	Gazeas et al. (2006)
024952+0856.3	1.380± 0.004	0.430± 0.002	1.350± 0.002	0.820± 0.001	1.490± 0.007	1.580± 0.009	Djurašević et al. (2006)
030953-0653.6	1.450± 0.044	0.540± 0.017	1.450± 0.018	0.910± 0.011	2.440± 0.061	1.030± 0.025	Qian et al. (2007b)
034814+2218.9	1.230± 0.004	0.540± 0.002	1.140± 0.002	0.790± 0.002	1.330± 0.004	0.610± 0.002	Yuan & Qian (2007)
062605+2759.9	1.674± 0.048	0.283± 0.022	1.897± 0.018	0.837± 0.009	4.279± 0.090	1.090± 0.058	Gazeas et al. (2005)
064558-0017.5	1.390± 0.070	0.930± 0.060	1.440± 0.030	1.290± 0.030	2.780± 0.011	1.080± 0.005	Gazeas et al. (2009)
071058-0352.8	1.528± 0.020	1.482± 0.020	1.738± 0.006	1.592± 0.007	8.446± 0.011	7.551± 0.012	Zola et al. (2004)
084002+1900.0	1.350± 0.020	0.610± 0.010	1.270± 0.040	0.890± 0.030	2.130± 0.110	1.260± 0.070	Zhang et al. (2009)
100234+1702.8	1.742± 0.047	0.586± 0.027	1.689± 0.015	1.004± 0.009	6.926± 0.043	2.073± 0.020	Gazeas et al. (2006)
105030-0241.7	1.423± 0.016	0.449± 0.009	1.497± 0.008	0.864± 0.006	2.174± 0.022	0.832± 0.008	Gazeas et al. (2006)
110505+0509.1	1.470± 0.000	0.440± 0.000	1.490± 0.000	0.870± 0.000	2.846± 0.000	1.003± 0.000	Qian et al. (2007a)
134607+0506.9	1.284± 0.015	1.046± 0.013	1.223± 0.005	1.107± 0.004	1.720± 0.002	1.500± 0.001	Zola et al. (2005)
141726+1234.1	0.980± 0.004	0.420± 0.002	1.080± 0.002	0.740± 0.002	1.100± 0.036	0.360± 0.006	Rainger et al. (1990)
141937+0553.8	1.730± 0.024	0.850± 0.017	1.717± 0.008	1.246± 0.007	5.905± 0.055	3.155± 0.060	Gazeas et al. (2005)
152243+1615.7	1.109± 0.038	0.192± 0.008	1.148± 0.007	0.507± 0.006	1.480± 0.010	0.340± 0.020	Zola et al. (2005)
153152-1541.1	1.060± 0.060	0.350± 0.030	1.170± 0.050	0.720± 0.030	1.360± 0.190	0.590± 0.050	Szalai et al. (2007)
165717+1059.8	1.191± 0.012	0.288± 0.009	1.392± 0.018	0.689± 0.009	1.782± 0.030	0.468± 0.011	Gazeas et al. (2006)
171358+1621.0	1.860± 0.010	0.480± 0.010	1.660± 0.010	0.960± 0.010	4.430± 0.010	0.970± 0.010	Samadi et al. (2010)
180921+0909.1	1.572± 0.031	0.462± 0.042	1.528± 0.010	0.874± 0.006	3.148± 0.020	1.097± 0.010	Gazeas et al. (2006)
193524+0550.3	1.377± 0.036	0.498± 0.022	1.314± 0.012	0.808± 0.008	1.796± 0.033	0.777± 0.041	Gazeas et al. (2006)
194813+0918.5	1.040± 0.002	0.880± 0.002	1.390± 0.002	1.290± 0.002	1.910± 0.039	1.560± 0.032	Hrivnak (1989)
222257+1619.4	1.420± 0.040	0.530± 0.020	1.290± 0.040	0.830± 0.020	1.860± 0.080	0.940± 0.060	Kalomeni et al. (2007)

0.38 day period in the Hipparcos photometric observations. Rucinski et al. (2002) correctly found that the source of variability is the southern, fainter companion, which is classified as a W UMa type eclipsing binary EE Cet ($P \sim 0.38$ days). In their radial velocity study, EE Cet was observed without contamination by the northern companion, separated by $5.6''$. They assigned a spectral class F8V to the system and classified it as a W-type W UMa binary with a mass ratio $q_{sp} = 0.315(5)$. A photometric study of this star was carried out by Djurašević et al. (2006) using $q = 0.315$ who obtained the parameters as listed in Table 7. They obtained $i[^\circ] = 78.5 \pm 0.2$, $M_1 + M_2 = 1.80 M_\odot$, $L_3 \sim 0.54$ and mass function $f(M) = 1.694 M_\odot$. This value of $f(M) = 1.694 M_\odot$ is quite close to the spectroscopically determined value $1.706(41) M_\odot$ of Rucinski et al. (2002). We have also used the same value of $q_{sp} = 0.315$ to model the ASAS light curve. Since the star is a W-type contact binary, we have used the inverse of q_{sp} in the photometric light curve modelling technique and obtained $i[^\circ] = 63.50 \pm 0.67$, $f(M) = 1.704(50) M_\odot$, $L_3 = 0.278 \pm 0.019$. The mass function $f(M)$ in all the three cases is quite similar. However, the absolute parameters determined using the ASAS light curve are different from those of Djurašević et al. (2006). This disagreement might be caused because of slightly noisy ASAS data and/or estimation of different values of third light contribution in the two analyses. Simultaneous multi-color photometry and the use of spectral broadening function using high resolution radial velocity curves can resolve the issue of accurate estimation of third light in the system. This will help in the determination of reliable parameters for this binary system.

6.3 ASAS 071058-0352.8 = V753 Mon

V753 Mon is a new discovery of the Hipparcos mission. The radial velocity measurements of the star were obtained by Rucinski et al. (2000) who found a spectroscopic mass ratio

of $q_{sp} = 0.970$. The star was classified as a W UMa binary of subtype-W with spectral type A8V by the authors. The recent photometric analysis of the star by Zola et al. (2004) yields the following parameters of the binary: $i[^\circ] = 75.30 \pm 0.13$, $\Delta T \sim 120$ K, using a semi-detached configuration with the slightly less massive component filling its Roche lobe. Our photometric analysis of the ASAS light curve also shows that the configurations of the system is not a contact one. The star is marked with the serial number ‘20’ in Fig. 5 and lies above the contact envelope. We have also found a semi-detached configuration with the secondary star filling its Roche lobe from the ASAS light curve modelling. We found : $i[^\circ] = 74.85 \pm 0.07$, $\Delta T \sim 104$ K. We now compare our mass function determination with Zola et al. (2004) and Rucinski et al. (2000). The physical parameters obtained by Zola et al. (2004) and those determined by us are listed in Table 8. The mass function estimated from Zola et al. (2004) is $2.724 M_\odot$ following equation (5). On the other hand, the mass function obtained from the ASAS light curve is $f(M) = 2.930(34) M_\odot$ and is identical to the spectroscopic estimate $2.93(6) M_\odot$ of Rucinski et al. (2000). However, the mass function derived from Zola et al. (2004) is quite different from both the spectroscopic estimate of Rucinski et al. (2000) and that determined by us. Therefore the parameters determined by Zola et al. (2004) need to re-examined.

6.4 ASAS 171358+1621.0 = AK Her

AK Her is the brighter component in the visual binary ADS 10408. The companion, located at a separation of $4.2''$, is 3.5 mag fainter than AK Her at its maximum light (Pribulla et al. 2006). The star has been the subject of numerous studies (Samadi et al. 2010, and references therein). These suggest that the system has a variable light curve and a variable period. Analysis of the updated $O - C$ curves revealed evidence of continuously changing period with cycle

Table 7. Parameters for the components of EE Cet and comparison with previous study.

Parameter	Djurašević et al. (2006)	This study
$q[\text{fixed}]$	0.315	0.315
$M_P(M_\odot)$	1.37(4)	1.808(126)
$M_S(M_\odot)$	0.43(2)	0.569(29)
$R_P(R_\odot)$	1.35(2)	1.456(12)
$R_S(R_\odot)$	0.82(1)	0.864(8)
$L_P(L_\odot)$	1.58(9)	2.445(400)
$L_S(L_\odot)$	1.49(7)	1.020(173)

Table 8. Parameters for the components of V753 Mon and comparison with previous study.

Parameter	Zola et al. (2004)	This study
$q[\text{fixed}]$	0.971	0.970
$M_P(M_\odot)$	1.528(20)	1.654(16)
$M_S(M_\odot)$	1.482(20)	1.604(28)
$R_P(R_\odot)$	1.738(7)	1.646(12)
$R_S(R_\odot)$	1.592(6)	1.935(12)
$L_P(L_\odot)$	8.446(68)	8.274(871)
$L_S(L_\odot)$	7.551(112)	12.067(1.288)

length between 57 and 97 years (Samadi et al. 2010). Using the spectroscopic mass ratio of 0.26 from Sanford (1934), Samadi et al. (2010) derived $i[^\circ] = 83.88 \pm 0.27$ and the parameters as listed in Table 9. Using the spectroscopic radial velocity measurements, Pribulla et al. (2006) obtained $K_1 = 70.52 \pm 1.12 \text{ km s}^{-1}$, $K_2 = 254.40 \pm 2.27 \text{ km s}^{-1}$. Pribulla et al. (2006) quoted $f(M) = 1.598(29)$, while the correct value should be 1.502(29), which can be calculated from equation (5). From Samadi et al. (2010), one can calculate the value of mass function $f(M) = (M_1 + M_2) \sin^3(i) = 2.300 M_\odot$. This value is quite different from the spectroscopic estimate 1.502(29). Hence, the parameters determined by Samadi et al. (2010) may not be reliable. We have analysed the ASAS light curve of AK Her using the spectroscopic mass ratio $q_{sp} = 0.277$, considering A-type configuration and a spectral type F4V (Pribulla et al. 2006). Using the ASAS data, we calculated the mass function for the system as $1.500(37)M_\odot$, which is nearly identical to the spectroscopic estimate of Pribulla et al. (2006).

Table 9. Parameters for the components of AK her and comparison with previous study.

Parameter	Samadi et al. (2010)	This study
$q[\text{fixed}]$	0.26	0.277
$M_P(M_\odot)$	1.86(1)	1.175(28)
$M_S(M_\odot)$	0.48(1)	0.326(14)
$R_P(R_\odot)$	1.66(1)	1.372(27)
$R_S(R_\odot)$	0.96(1)	0.775(7)
$L_P(L_\odot)$	4.43(1)	3.531(489)
$L_S(L_\odot)$	0.97(1)	0.760(82)

7 VARIOUS RELATIONS OF CONTACT BINARIES

7.1 Period-mass relation for contact binaries

Various studies suggest that there exists a period-mass relation for contact binaries (Qian 2003; Gazeas & Stępień 2008; Gazeas & Niarchos 2006). Qian (2003) noted that the mass of the primary component (more massive) increases linearly with increasing period. Gazeas & Niarchos (2006) also noted the same and found that the mass of the secondary component (less massive) is nearly period independent and varies between 0 and $1 M_\odot$. From a sample of 112 binaries (52 W-type and 60 A-type), Gazeas & Niarchos (2006) derived the following relations between the masses of the components and the orbital period (P):

$$\log M_P = (0.755 \pm 0.059) \log P + (0.416 \pm 0.024), \quad (6)$$

$$\log M_S = (0.352 \pm 0.166) \log P - (0.262 \pm 0.067). \quad (7)$$

In Fig. 10, we have plotted $\log M_P$ versus $\log P$ and $\log M_S$ versus $\log P$ for the 54 contact binaries in our sample. Also overplotted are the solid lines from the relations of equations (6) & (7) in this paper obtained by Gazeas & Niarchos (2006). It can be seen that the masses of the primary components, in general, obey the period-mass relation defined by equation (6), whereas, the secondary components do not seem to obey any strict period-mass relation of equation (7) as derived by Gazeas & Niarchos (2006).

7.2 Period-color relations of contact binaries

Contact binaries obey a well-defined period-color relation. This relation plays a special role in the study of their properties (Rucinski 1997b, 2000). The period-color relations of equal mass marginal contact binaries over a wide range of age and metallicity were studied by Rubenstein (2001). Rucinski (2000) derived the shapes of short period blue envelopes (SPBEs) for disk systems by the following two power law relations:

$$(B - V) = 0.04P^{-2.25} \quad (8)$$

and

$$(V - I) = 0.053P^{-2.1} \quad (9)$$

Here we examine the period (P)-infrared color ($J - K$) relation of 141 contact binaries. The relation that we derive here is just a power law fit to the data in the $P - (J - K)$ plane, whereas Rucinski's SPBE is rather a limit for color and period of stars. Because of the advantage of ($J - K$) color not effected by the interstellar extinction and uncertain reddening corrections as compared to the ($B - V$) color, the period-color relation using the infrared color ($J - K$) will be helpful for larger databases, where the period can be determined easily with greater accuracy. In the present study, the infrared color is obtained from the JHK magnitudes in the 2MASS point source catalog (Cutri et al. 2003). To increase the number of samples to derive the $P - (J - K)$ relation, we took 129 W UMa contact binaries from Bilir et al. (2005). For one star, GZ And, in the sample, there is no reliable JHK magnitude available in the 2MASS catalog. On the other hand, two stars in the Bilir's sample, V753 Mon and

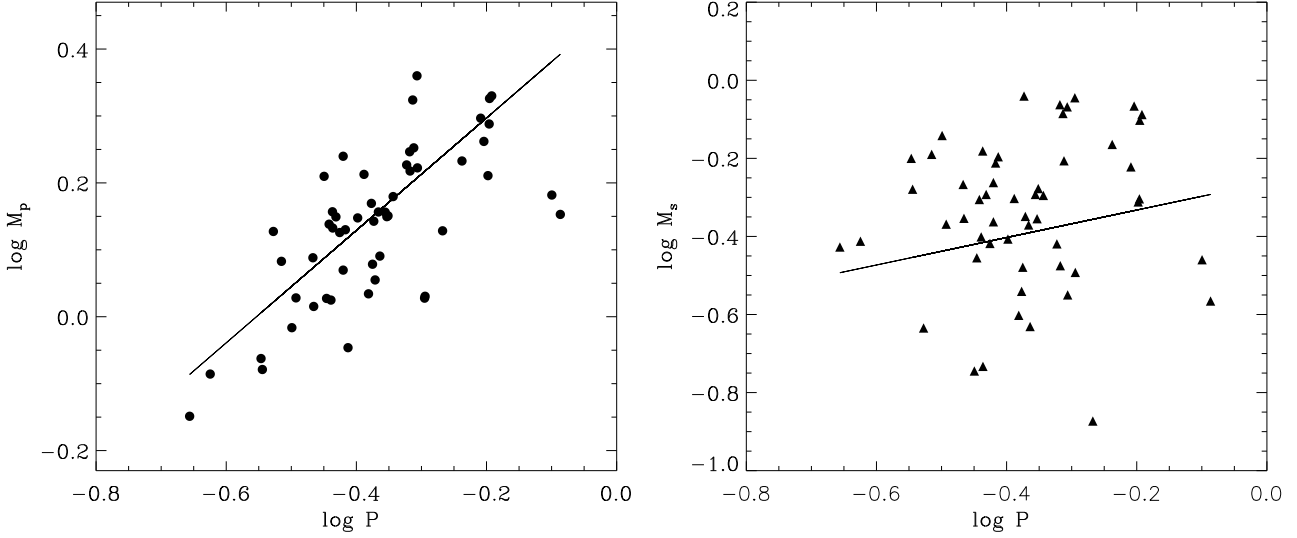


Figure 10. The left and right panels show the masses of the primary and secondary components of 54 contact binaries in our sample on the $\log P$ - $\log M_p$ and $\log P$ - $\log M_s$ plane. Solid lines in the two plots are the linear fits from equations (6) and (7) as derived by Gazeas & Niarchos (2006).

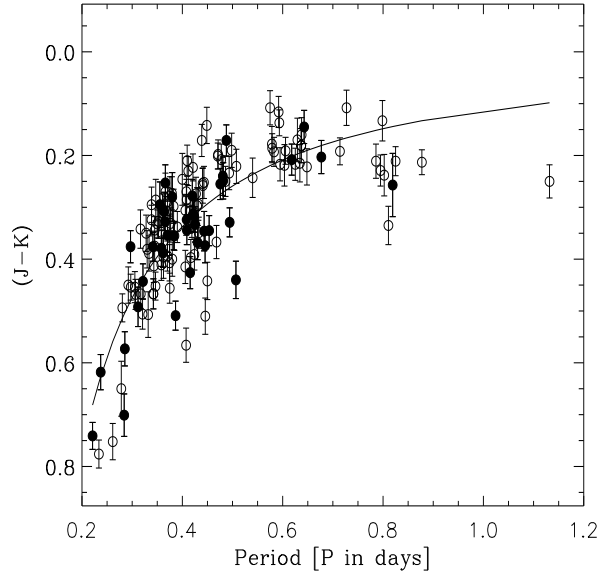


Figure 11. Period(P)-color ($J-K$) relation of 141 contact binaries obtained from the combined data of 54 ASAS contact binaries and data from Bilir et al. (2005). The 39 stars common to our sample are shown by filled circles. Solid line is the power law fit to the data of these contact binaries as given in equation (10).

HT Vir turned out to be semi-detached binaries in our analysis. Therefore, these three stars were rejected for deriving the period-infrared color relation of contact binaries. Hence, out of 129 stars in the Bilir's sample, we have selected 126 stars for the analysis. On the other hand, among 126 stars, 39 of them are common to our sample of 54 contact binaries. Therefore, the total sample used for deriving the ($J-K$) vs P relation for contact binaries is 141. Fig. 11 shows the period-color ($J-K$) for all the 141 contact binaries in the total sample. From the figure, it is very clear that contact

binaries definitely obey a tight period (P)-color ($J-K$) relation. From the 141 contact binaries, we derived the following relation

$$(J-K) = (0.11 \pm 0.01)P^{-1.19 \pm 0.08} \quad (10)$$

The fit to this derived relation is shown by solid line in Fig. 11. Derivation of such an empirical period-color relation of contact binaries using accurate infrared colors will be very useful to display the properties of contact binaries discovered in large photometric surveys. However, the derivation of

precise period-color relations of contact binaries need highly accurate age and metallicity estimations (Rubenstein 2001).

7.3 M-R and M-L diagrams

Fig. 12 shows the location of the components of detached binaries on the theoretical mass-radius (M-R), mass-luminosity (M-L) diagrams along with the 0.06, 0.50, 2.0, 5.0 and 10 Gyr theoretical isochrones from Girardi et al. (2000) for the population I stars with the solar composition (X, Y, Z) = 0.708, 0.273, 0.019. Each isochrone is plotted as a solid line and labelled with its corresponding age. Primary (more massive) components are plotted with filled circles and secondary components (less massive) with filled upper triangles. The components of the same pair are connected with dotted lines. We have not tried to estimate the ages of the components of contact binaries. The ages of the primary components can be determined by interpolation from the isochrone fitting. As in general, to an approximation, they obey a normal mass-radius relations for main sequence stars. On the other hand, the secondary components of contact binaries are always overluminous and oversized for their mass and do not obey the normal main sequence mass-radius relations. Hence it is difficult to calculate their age from the main sequence isochrone fitting. However, the peculiar evolutionary status of the contact binaries due to the effect of vast amount of mass transfer is also seen. The result of such effect is the underluminous and undersized primary component and overluminous and oversized secondary component Zhang et al. (2009). In fact it would be wrong to make comparisons between the empirical data on mass and absolute dimensions for such systems and the theoretical stellar evolution of single stars alone. The stellar evolution theory is very much complicated which takes into account the mass loss, the existence of the upper limit of the volume of a star and to allow for changes in orbital period and sizes due to the effect of mass transfer for semidetached and contact binaries and is beyond the scope of this present work. For the two detached binaries in our sample, 203113+0513.2 appears to have an age ≥ 10 Gyr, whereas, 084108–3212.1 has an age ≤ 0.5 Gyr from the M-R diagram. However, determination of their accurate ages need parameter estimations from highly precise light curves.

8 SUMMARY AND CONCLUSIONS

We have explored the ASAS database to study the eclipsing binaries. We have presented a detailed analysis of the light curves of 62 eclipsing binaries monitored by the ASAS project which have precise radial velocity measurements in the literature.

We updated the ASAS periods using the ME method and classified the stars based on their light curve shapes. With the improved ASAS periods, we obtained significant improvement in the light curve shapes. For preliminary classification, we have used cosine decomposition of the light curves into the Fourier coefficients, where contact, semidetached and detached configurations can be distinguished in the a_2 – a_4 plane. Further, using the Roche lobe geometry, we found that the sample contains 54 contact, 6 semidetached and 2 detached binaries. The physical parameters of all the

62 binaries were calculated using the WD light curve modelling technique. Spectroscopic mass ratios of these binaries available in the literature were used for their modelling. Out of 62 stars in the sample, light curve analysis of 39 stars are presented here for the first time using combined photometric and spectroscopic data. For majority of remaining 23 stars, the determination of parameters are found to be consistent with the earlier values obtained in the literature. Thus, ASAS-like databases can, in general, be used for parameter determinations of newly discovered eclipsing binaries for statistical analysis. ASAS-like database opens a new avenue to study the parameters of eclipsing binaries in large numbers. Availability of data of a huge number of eclipsing binaries in these databases will facilitate for measurements of their geometrical and physical parameters, if precise mass ratios are determined from spectroscopy. Spectroscopic measurements combined with the photometry from large databases will provide an opportunity to understand the origin and evolution of binaries accurately and will resolve the long-standing issues of formation and evolution of contact binaries. It is therefore an urgent need to come up with projects which will be solely devoted to radial velocity measurements of eclipsing binaries discovered in various automated photometric surveys and hence enhance our knowledge about the formation, structure and evolution of stars.

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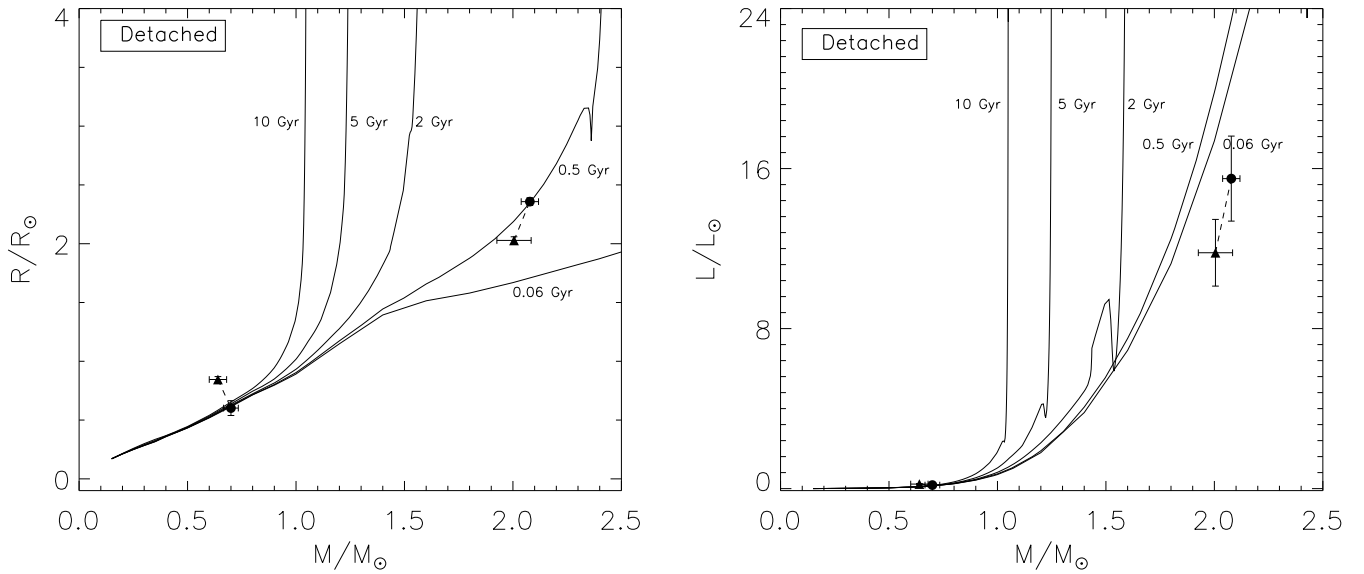


Figure 12. Location of the components of detached binaries on the theoretical mass-luminosity (M-L) and mass-radius (M-R) diagrams along with the 0.06, 0.50, 2.0, 5.0 and 10 Gyr theoretical isochrones from Girardi et al. (2000) for the population I stars with the solar composition (X, Y, Z) = 0.708, 0.273, 0.019. Each isochrone is plotted as a solid line and labelled with its corresponding age. Primary (more massive) components are plotted with filled circles and secondary components (less massive) with filled upper triangles. The components of the same pair are connected with dotted lines.

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